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EDITOR'S NOTE

After several years as Editor of **Transactions**, Dr. J. E. House, Jr., has stepped down. Certainly, the Illinois State Academy of Science owes Dr. House a great measure of gratitude for his unflagging efforts.

This issue of **Transactions** represents the final group of papers accepted for publication under Dr. House's editorship, and your new editor acknowledges that his was not the work which went into this particular issue.

Basil C. Hedrick
Editor

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PHYSICAL CHARACTERISTICS OF MALE AND FEMALE EASTERN BOX TURTLES (*TERRAPENE CAROLINA CAROLINA*) FOUND IN ILLINOIS

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ABSTRACT

Fifteen physical characteristics were measured in each of 44 specimens of the Eastern box turtle (*Terrapene carolina carolina)* collected in Vermilion and Crawford counties, Illinois. Male turtles differed from females in having a greater dorsal shell (carapace) front straight width, a smaller carapace middle height, a concavity in the ventral shell (plastron), a shorter tail length, and a red iris color. An empirical equation for estimating age from carapace straight length was developed. The dimensions, markings and shapes of carapace epidermal shields (scutes) were quantified.

FOREWORD

We thank Patricia Berg and Nick Kondelis for their care of the animals. The research was supported by the Biology Department, Knox College, Galesburg, Illinois, 61401. The final typing was done by Mrs. Mary Schultz. Please address all correspondence on this paper to Dr. R.E. Johnson, Department of Biology, Knox College, Galesburg, Illinois 61401

INTRODUCTION

In physical systems the fundamental measurements are mass, length, breadth, height, and changes with time. These measurements are also fundamental for biological systems. As expressed by Yales (1979): ''Similarity analysis permits comparison of the structures and functions of two different objects (model and prototype; individual members of two different species, etc.)''. We have studied the physical characteristics of the Eastern box turtle which is abundant in the southern half of Illinois (Smith, 1961) and have tried to generalize on differences between males and females, on correlations between age and body dimensions, and on the patterns and markings of the carapace epidermal shields (scutes). According to Auffenberger and Iverson (1979), the body dimensions of this terrestrial animal have not been studied extensively, although the species is widespread in North America.

MATERIALS AND METHODS

Animals:

Thirty-four female and 10 male Eastern box turtles *(Terrapene carolina carolina),* were collected by hand in Vermilion and Crawford counties (longitude 88°W, latitude 39°N) in Illinois, during the spring of 1975 and 1977. All turtles encountered were collected and transferred to the laboratory. Measurements were taken within 10 days of capture. All animals appeared to be in good health. The methods of Smith (1961) were used to determine turtle genus, species, and sex.

Measurements:

Turtle shell demensions were measured at 12 locations of both the dorsal shell (carapace) and the ventral shell (plastron). The descriptions of procedures presented in standard works for measuring turtle shells are sometimes imprecise or ambiguous. Therefore the following 5 commonly used turtle measurements are defined using the method of Rothschild (1915) and the nomenclature of Zangerl (1969).

1. The straight length of the carapace is the length measured form the anterior tip of the cervical scute to the posterior tip of the 12th marginal scute.

2. The straight width of the carapace is the distance from the left lateral border of the 6th marginal scute through the border of the 2nd and 3rd vetebral scutes to the right lateral border of the 6th marginal scute.

3. The front straight width of the carapace is the distance from the left lateral border of the 5th marginal scute through the border of the 1st and 2nd vetebral scutes to the right lateral border or the 5th marginal scute.

4. The length of the ventral plastron is the distance measured from the anterior tip of the intergular scute to the posterior tip of the anal scute.

5. The middle height of the carapace is the distance from the bottom of the plastron to the top of the carapace using the border of the 2nd and 3rd vertebral scutes as a reference point. In addition to these shell measurements, iris color, tail length, body weight, and scute markings were recorded.

Materials:

The measuring instruments were a steel flexible ruler, a tape measure, an electronic top loading balance (Mettler) and a machinist's caliper. A magnifying glass was used to observe the carapace and scute markings.

Markings of the Scutes:

In studying the carapace markings and scutes the anatomical rules of Zangerl (1969) were used. The left second pleural scute was chosen for tabulation on the ground that it is the most geometrically regular of the scutes. Pleural scute dimensions were measured with a flexible ruler and the growth rings were counted with a magnifying glass. The total number of discrete markings were subdivided into ovoid, linear and irregular markings. Pleural scute area was calculated with Simpson's rule for irregular plane figures.

Statistical Methods:

Differences between male and female physical characteristics were compared by the "t" test (Moroney, 1965, p. 232). The fiducial limit of significance was taken as 0.05. The correlation between turtle age and shell length was studied by empirical curve fitting techniques (Moroney, 1965, p. 271).

RESULTS

The measurements of turtle body dimensions are summarized in Table 1. In this sample of 34 female and 10 male animals sexual dimorphism was demonstrated as follows:

1. Male turtles had a greater carapace front straight width, a lower carapace middle height, a concavity on the posterior plastral lobe, a shorter tail, and a red iris color.

2. Female turtles had a smaller carapace front straight width, a higher caracpace middle height, longer tails, a flat ventral plastron, and a brown iris color.

Young male turtles having a plastron length of less than 100 mm did not always show the concavity of the plastron shell.

Unless a turtle has been kept under observation since birth or infancy the estimation of its age has generally been made from measured physical characteristics. In Figure 1. carapace length is plotted against known turtle age as reported by Kaplan (1974) and Nichols (1939) for *Terrapene carolina carolina.* The relationship is curvilinear. Satisfactory correlations are obtained with either an exponential (Equation 1.) or a power (Equation 2.) relationship.

$$Y = 1.3 - e^{\frac{0.1X}{100}} \qquad \text{(Equation 1)}$$

$$Y = 30X^{0.36} \qquad \text{(Equation 2)}$$

Where "Y" is the carapace length in mm and "X" is age in years.

The exponential equation assumes an asymptote at a carapace length of 130 mm, which seems unlikely. The power equation assumes that growth slows progressively but does not cease entirely even in very old animals. Equation 2. is preferred as the more reasonable prediction of age from carapace length, recognizing it to be a crude approximation as judged by this equation.

We estimate the mean age of the male turtles as 70 years, (range 50 to 100) and the mean age of the female turtles as 60 years (range 16 to 122).

The observations on scutes and markings are summarized in Table 2. The second pleural scute is an elongated pentagon, with two long sides (anterior and posterior) and three short sides (lateral, antero-medial, and postero-medial). Rarely, the lateral side is in two segments, an anterior and a posterior.

The description of the markings has to be subjective and, to a degree, arbitrary. Generally, they are pale on a brown background. However, a few animals show the opposite, brown on a pale background. It is convenient to classify them as ovoid, linear, or irregular. Although they are similar on the left and right for the same scute, the patterns are not identical. As Table 2 shows, with respect to the left second pleural scute, the variation from one animal to another is great.

The growth rings of the pleural scutes are widest in the neighborhood of the embryonic center. This lies medially and a little posteriorly in the scute. From there the growth rings are most prominent laterally and anteriorly; they are tightly squeezed posteriorly and medially from embryonic center. A plot of the width of the rings, moving laterally from the center, against the order in which the ring lies, gives an exponential curve, with an asymptote of about 0.2 mm. This implies that the growth rings are increasingly narrow with age, until they hardly grow at all.

DISCUSSION

Four aspects of the characteristics of body dimensions of *Terrapene carolina carolina* will be discussed: the general value of measurement, the differences between males and females, the problems of estimating the age of a given specimen, and finally, the patterns and markings of the carapace scutes. Other aspects of turtle biology are discussed by Altman and Dittmer (1966), Dill et al. (1964), Gans et al. (1969), Harless and Morlock (1979), and Morris (1974).

1. The general value of measurement.

In an attempt to describe the turtle body in physical terms, we have had no difficulty with mass, length, breadth, and height. We should like to add volume, and from this, the density. So far, no method has been found by which the respiratory and gastrointestinal gas components, and the nonpulmonary air under the carapace (Patterson, 1976) can be estimated. The present measurements are more complete in variety than previously reported for *Terrapene carolina carolina.*

2. Male and female sexual dimorphism.

We agree with Smith (1961) that significant differences exist between male and female turtles. This turtle sample had a sex ratio of 1 male to 3.4 females. Unequal reptilian sex ratios have been reported by others including Forbes (1940).

3. Turtle age.

Any study of the physical properties of an animal must include an estimate of the individual age. This is a difficult problem for all animals, especially those that live long, and *Terrapene carolina carolina* lives as long as any animal for which reliable data exist (Babcock, 1971). There is no completely satisfactory method to estimate a turtle's age. Some workers use the body weight for this estimate (Cahn, 1937; Ernst, Barbour, Ernst and Butler, 1973; Smith, 1961). Some observers believe that the growth rings of the scutes can be used to estimate the age (Kaplan, 1974; Zangerl, 1969) but we find this count to be technically difficult, and have strong reservations about its interpretation. Growth rings have been used to obtain a rough estimate of turtle age by Cagle (1948), who states that the counting of these annual growth rings is only reliable under conditions of rapid shell growth and should be used with caution.

According to Smith (1961) shell proportions can be used to distinguish turtle age into classes of juveniles, subadults, and adults. Melby and Altman (1977) have correlated carapace length with age. Babcock (1939), Ewing (1939), Nichols (1939), Edney and Allen (1951), and Carr (1953), have correlated turtle age with shell measurements. We have drawn on data of Kaplan (1974) and Nichols (1939) to derive an empirical curvilinear equation that predicts the age of the turtle from the straight length of its carapace (Equation 2, Figure 1).

Biddle's hypothesis is that two types of lifetime growth may be indentified for turtles (Comfort, 1964). The first, found in aquatic carnivores, presents a growth to a maximum after which no further growth occurs. The second type is found in terrestrial omnivores, and presents growth throughout life with a steady decrease in the annual rate. *Terrapene carolina carolina* probably fits into this catagory. Sergeev (1937) studied *Emys orbicularis* and we find his data correlated closely with an empirical exponential equation (Figure 2), which implies that the animal reaches a maximum growth and then does not change thereafter. We have not estimated turtle age from radionuclide decay, including radium, thorium, lead, uranium, carbon, or calcium, as used for vesicomyid clams by Turekian, Cochran, and Nozaki, (1979) nor have we had access to measurements of isomerization of aspartic acid in dentine as used by Bada and Masters (1979), to estimate the ages of humans, whales, porpoises, polar bears and elephants.

4. Patterns and markings of carapace scutes.

Few investigators have paid much attention to the markings on the scutes, usually dismissing them as extremely variable. Yet the data that may be obtained from them may be useful in at least two ways. First, the markings are more pronounced and individualistic in *Terrapene carolina carolina* than in any other turtle, and so the scutes help in recognition. Second, the markings are so different from one animal to another that they are useful in identifying an individual turtle, just as the extremely variable fingerprint is useful for human beings. The only other terrestrial turtle with conspicuous marking is *Terrapene ornata* which has only linear markings, some on the plastron. These are not nearly so elaborate as those of *Tereapene carolina carolina.* We have one reservation, because we do not know whether or not these markings are permanent through life. Perhaps they change from year to year.

If we assume that these markings have survival value, two possible functions come to mind. They could act as camouflage in woodlands, especially when leaves are brown or yellow, as in the autumn. They can and do act as solar panels, for these animals regulate their heat flux by behavorial activities, moving into and out of sunlight, as well as by metabolic changes related to muscular activity. The dark markings are absorbers, the light markings transmit at a wavelength of around 600 nm.

We are not satisfied that one growth ring is laid down per year, and we are not certain that they may not change from year to year if the material of the scute is shed.

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Table 1.—15 Physical Characteristics* of the Eastern Box Turtle, *Terrapene carolina carolina*

	Males N = 10			Females N = 34		
Physical Characteristics	Mean	Range	Standard deviation	Mean	Range	Standard deviation
Straight Length (mm)	137	(125-150)	7.9	132	(100-161)	10.8
Straight Width (mm)	103	(96-111)	5.2	101	(75-112)	6.8
Front Straight Width (mm)	94	(85-103)	6.1	89	(69-100)	6.1
Rear Straight Width (mm)	100	(89-113)	7.6	96	(73-116)	9.2
Length over Curve (mm)	170	(149-187)	12.0	165	(127-186)	13.1
Width over Curve (maximum, mm)	164	(128-188)	9.9	171	(112-167)	15.5
Width over Curve (minimum, mm)	150	(131-162	21.2	147	(123-193)	13.0
Plastron Length (mm)	140	(129-157)	9.5	135	(103-151)	11.6
Middle Height (mm)	61	(58-70)	4.5	66	(47-76)	7.1
Front Height (mm)	40	(37-45)	4.0	39	(27-50)	5.2
Height to Marginals (maximum, mm)	24	(17-26)	2.8	25	(17-30)	3.0
Height to Marginals (minimum, mm)	11	(7-16)	2.8	12	(6-17)	2.8
Tail Length (mm)	13	(7-18)	4.0	16	(7-23)	3.5
Body Weight (g)	450	(348-561)	74.7	458	(206-637)	86.6

*Measurements as described by Rothschild, 1915.

TABLE 2. Physical Characteristics of the Second Left Pleural Scute, 13 specimens of *Terrapene carolina carolina*.

Characteristic	Mean	Maximum	Minimum
Growth rings, number	19	23	8
Markings, number			
Total	9	18	1
Ovoid	3	8	0
Linear	2	7	0
Irregular	4	11	1
Length, Maximum, mm	56	68	35
Width, Maximum, mm	34	44	17
Area, cm^2	17.4	24.6	5.4
Sides, mm			
Anterior	45	55	27
Posterior*	45	52	28
Lateral	33	39	20
Antero medial	18	22	10
Postero medial	16	20	10

*Rarely the lateral border has two sides, a lateral anterior and a lateral posterior; however, it has a single straight side in most specimens.

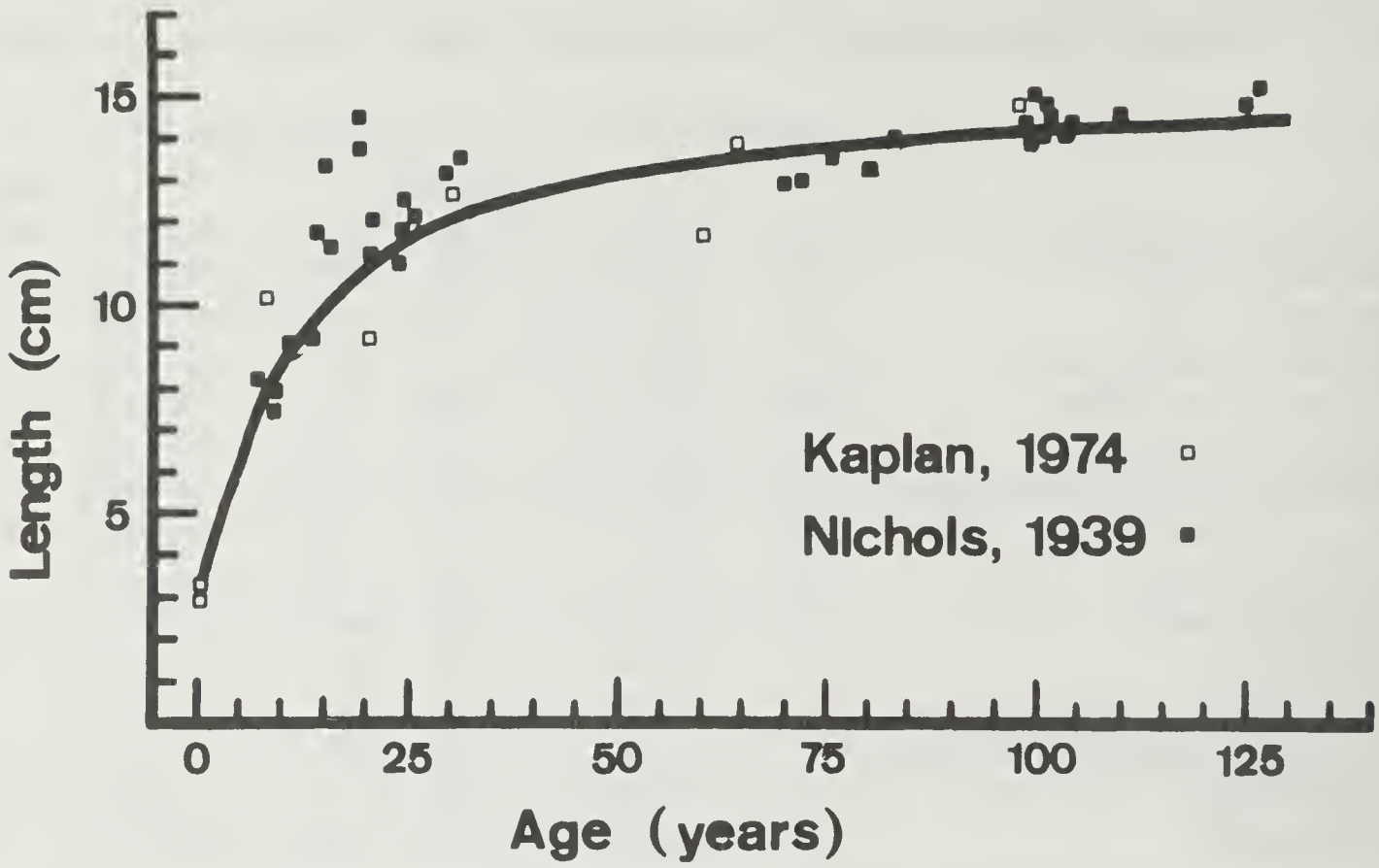

Figure 1. Estimated age of Eastern box turtles *(Terrapene carolina carolina)* compared with carapace length. (Data from Melby and Altman, 1977, Vol. 1,317, and from Kaplan, 1974, p. 285) The empirical curve is hyperbolic.

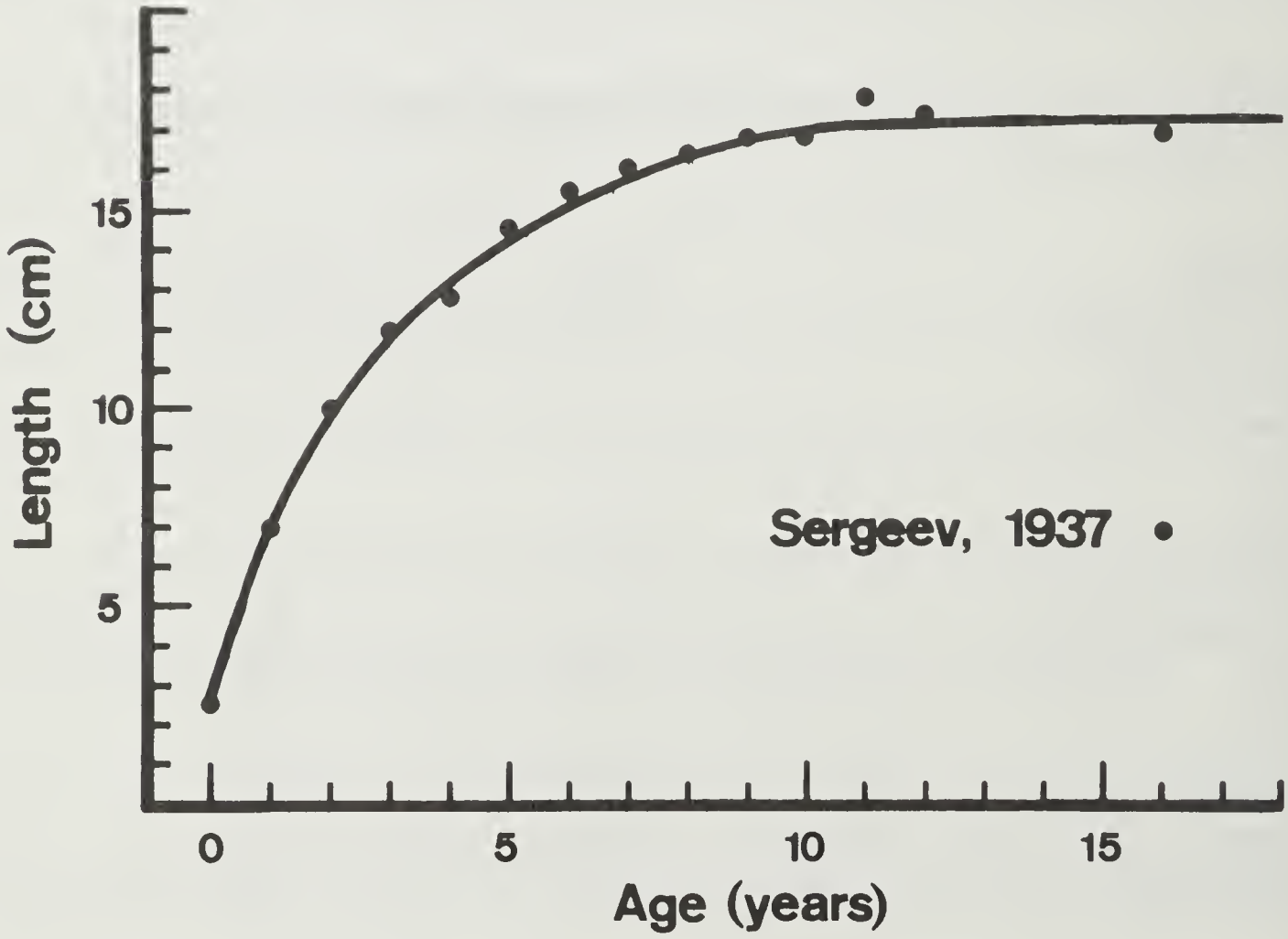

Figure 2 Data of Sergeev (1937) for the age and carapace length of *Emys orbicularis.* (European pond turtle). The empirical curve is exponential.

AN ANNOTATED LIST OF VASCULAR PLANTS FROM KNOX COUNTY, ILLINOIS

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ABSTRACT

A total of 712 species of vascular plants are reported from Knox County, Illinois, many for the first time. Of these taxa, 138 are introduced, or about 19% of the flora. The largest families, with their respective numbers of species, are Compositae (113), Gramineae (74), Cyperaceae (39), and Rosaceae (31). Notes on habitat, abundance, and representative specimens are given whenever possible.

INTRODUCTION

Knox County is located in northwestern Illinois about 40 miles south of Rock Island and 40 miles east of Burlington, Iowa. The county seat and largest incorporated area is the city of Galesburg. The county covers approximately 1,144 square kilometers, with an average elevation of 220 m. Nowhere is the relief very great, although there are some small bluffs and steep slopes along major streams. The north and west sectors of the county are relatively level or slightly undulating. These areas at one time supported a lush tall grass prairie, the only reminders of which can be seen in a few cemeteries, in scattered patches along the railroads, and in the black fertile soil which supports modern agriculture.

To the south and east, the land is much more dissected by streams, with the Spoon River flowing through the southeastern quadrant and forming the major drainage system in the county. This part of Knox County is covered by woodlands of oak, hickory, and maple, all of which have been heavily disturbed by man's activities. The ecotonal zones between the woodlands and the upland prairies, termed ''barrens'' by the early settlers, were characterized by an alternation of fingers and patches of forest with grassland. The Spoon River floodplain, and those of its larger tributaries, provide a few aquatic habitats. However, for the most part, these wetlands have been drained for agricultural purposes.

Man's activities, primarily in the form of farming, have substantially altered the distribution and composition of the vegetation within Knox County. A second, severe form of disturbance, which has taken place over the years, is the extensive strip mining in the eastern and southern parts of the county. Despite these disruptive factors, the flora of Knox County remains relatively rich. However, many of the species included in the checklist are known from only one or two stations, and, in the author's opinion, are becoming rarer each year and may soon disappear entirely from the region.

ANNOTATED LIST

This checklist of vascular plants enumerates 712 species, of which 138 (19%) are introduced. 211 taxa are newly recorded for the county, based on the information given in Mohlenbrock and Ladd (1978). In the list, the new records are indicated by a '+', while introduced taxa are denoted by an '*'. The four largest families represented are Compositae (113), Gramineae (74), Cyperaceae (39), and Rosaceae (31), accounting for 36% of the flora. A subjective listing of

habitats and abundance is given whenever possible, along with representative specimens. The nominclature follows that of Mohlenbrock (1975) for the most part, but with additional reference to Jones (1963) and Gleason and Cronquist (1963).

All of the specimens cited are disposited in the Herbarium at Knox College (KNOX), unless otherwise noted* Collection numbers are those of the author, except where indicated. For the sake of completeness, in addition to the cited specimens, the list includes county records taken from Mohlenbrock and Ladd (1978), indicated by the leters 'M-L', and a number of sight records for species which were exceedingly rare, or were, for a variety of reasons, never collected.

VASCULAR CRYPTOGAMS

EQUISETACEAE

Equisetum arvense L. Streambanks, sandy soil; common; 16.
Equisetum x *ferrisii* Clute. Railroad ballast; Winterringer s.n. (ISM).
Equisetum hyemale L. Banks of ponds, streams, spoilbanks; common; 514.
Equisetum laevigatum A. Br. M-L.

OPHIOGLOSSACEAE

+*Botrychium disectum* Spreng. var. *obliquum* (Muhl.) Clute. Ravines, upland woods; infrequent; 1332.
Botrychium virginianum (L.) Sw. Upland woods; frequent; 220.

OSMUNDACEAE

Osmunda claytoniana L. Moist ravines, upland woods; rare; 1162.

POLYPODIACEAE

Adiantum pedatum L. Ravines, rich woods; frequent; 235.
Athyrium filix-femina (L.) Roth. Ravines, upland woods; frequent; 892.
Athyrium thelypteroides (Michx.) Desv. Woods; M-L.
Cystopteris fragilis (L.) Bernh. Rich woods; common; 234.
Dryopteris carthusiana (Villars) H.P. Fuchs. Ravines, upland woods; frequent; 748.
Onoclea sensibilis L. Wet ravines, marshes; infrequent; 495.
Pteridium aquilinum (L.) Kuhn. Woods; M-L.

GYMNOSPERMAE

CUPRESSACEAE

+*Juniperus virginiana* L. Dry woods, old fields; frequent; 894.

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*LFC = Lake Forest College Herbarium, Lake Forest, Illinois. Other herbaria follow the abbreviations in Holmgren and Kueken (1974).

ANGIOSPERMAE

TYPHACEAE

+*Typha anguistifolia* L. Marshes, ponds, frequent; 860.
Typha latifolia L. Marshes, ponds, common; Weik B83 (LFC).

SPARGANIACEAE

+*Sparganium androcladum* (Engelm.) Morong. Lake margin; Weik B99 (LFC).
+*Sparganium eurycarpum* Engelm. Wet ground; Weik B45 (LFC).

NAJADACEAE

Najas flexilis (Willd.) Rostk. & Schmidt. Shallow ponds, lakes; M-L.
Najas guadalupensis (Spreng.) Magnus. Shallow ponds, lakes; Russel s.n. (ISM).

POTAMOGETONACEAE

**Potamogeton crispus* L. Shallow ponds, lakes; common; Russel s.n. (ISM).
Potamogeton foliosus Raf. Shallow ponds, lakes; common; 829.
+*Potamogeton illinoiensis* Morong. Shallow ponds, lakes; Russell s.n. (ISM).
Potamogeton nodosus Poir. Shallow ponds, lakes; common; 815.
Potamogeton pectinatus L. Shallow ponds, lakes; Russell s.n. (ISM).
Potamogeton pusillus L. Shallow ponds, lakes; common; 740.

ZANNICHELLIACAE

+*Zannichellia palustris* L. Shallow ponds, lakes; frequent; 741.

ALISMATACEAE

+*Alisma plantago-aquatica* L. var. *americana* Roem. & Schult. Shallow ponds, lakes; Weik B80 (LFC).
+*Alisma subcordatum* Raf. Shallow ponds, ditches; frequent; 980.
+*Echinodorus rostratus* (Nutt.) Engelm. Shallow ponds, marshes; frequent; 1100.
Sagittaria brevirostra Mack. & Bush. Marshes, ponds; M-L.
+*Sagittaria latifolia* Willd. Marshes, ponds; 1176.

HYDROCHARITACEAE

Elodia nuttallii (Planch.) St. John. Shallow ponds, lakes; 820.

GRAMINAE

**Agropyron repens* (L.) Beauv. Waste areas, roadsides; common; 851.
+*Agrostis hyemalis* (Walt.) BSP. Dry fields, roadsides; frequent; 257.
Agrostis stolonifera L. Dry open woods, spoilbanks; 757.
Andropogon gerardi Vitm. Prairie remnants, railroads; frequent; 310.
Aristida oligantha Michx. Dry soils, railroads; M-L.
**Arrhenatherum elatius* (L.) Presl. Fields, roadsides; M-L.
**Avena sativa* L. Railroads, roadsides; occasional; 1030.
Bromus inermis Leyss. Old fields, roadsides; common; 727.

+ **Bromus japonicus* Thunb. Old fields, waste places; common; 223.
Bromus pubescens Muhl. Upland woods; 886.
Bromus purgans L. M-L.
**Bromus secalinus* L. Old fields, roadsides; M-L.
**Bromus tectorum* L. Dry fields, roadsides; Fach 68 (ISM).
+*Calamagrotis canadensis* (Michx.) Beauv. Wet ground; Weik B50 (LFC).
+*Cenchrus longispinus* (Hack.) Fern. Dry sandy soil; infrequent; 1278.
Cinna arundinacea L. Moist woods; 1341.
**Dactylis glomerata* L. Old fields, roadsides; common; 484.
+*Diarrhenia americanna* Beauv. Upland woods; 1064.
+ **Digitaria ischaemum* (Schreb.) Muhl. Waste places, yards; frequent; 1206.
**Digitaria sanguinalis* (L.) Scop. Waste places, yards; common; sight record.
+ **Echinochloa crus-gali* (l.) Beauv. Waste places, roadsides; common; 1089.
Echinochloa.pungens (Poir.) Rydb. Wet banks; 294.
**Eleusine indica* (L.) Gaertn. Waste places, yards; common; M-L.
Elymus canadensis L. Dry soils, railroads, prairies; frequent; 1091.
Elymus villosus Muhl. Upland woods; frequent; 883.
Elymus Virginicus L. Old fields railroads, common; 867.
**Eragrostis cilianensis* (All.) Mosher. Old fields; M-L.
Eragrotis pectinacea (Michx.) Nees. Old fields, waste places; M-L.
Eragrostis spectabilis (Pursh) Steud. Sandy soil; M-L.
Festuca obtusa Bieler. Upland woods; frequent; 761.
**Festuca pratensis* Huds. Old fields, roadsides; M-L.
+*Glyceria septentrionalis* Hitchc. Marshes, wet ground; Weik B107 (LFC).
Glyceria striata (Lam.) Hitchc. Wet woods, stream banks; frequent; 799.
+ **Holcus lanatus* L. Old field; infrequent; 492.
**Hordeum jubatum* L. Old fields, waste places; common; 881.
Hordeum pusillum Nutt. Dry soils, old fields; common; 770.
Hystrix patula Moench. Open dry woods, prairies; 1071.
Koeleria macrantha (Ledeb.) Spreng. Sandy soils, prairies; M-L.
+*Leersia oryzoides* (L.) Sw. Marshes, wet ground; infrequent; 1182.
Leersia virginica Willd. Moist woods; M-L.
Melica nitens (Scribn.) Nutt. Dry open woods, prairies; M-L.
+ **Miscanthus sacchariflorus* (Maxim.) Hack. Open stream bank; occasional escape; 1193
Muhlenbergia frondosa (Poir.) Fern. M-L.
Muhlenbergia mexicana (L.) Trin. Moist woods; M-L.
+*Muhlenbergia schreberi* J. F. Gmel. Waste places, yards; sight record.
+*Muhlenbergia sobolifera* (Muhl.) Trin. Dry Woods, spoilbanks; frequent; 1344.
Panicum capillare L. Old fields, waste ground; M-L.
Panicum dichotomiflorum Michx. Moist fields, waste places; M-L.
Panicum lanuginosum Ell. Old fields, open woods; common; 227.
Panicum latifolium L. Upland woods; 1044.
Panicum leibergii (Vasey) Scribn. Prairie remnants; infrequent; 861.
+*Panicum oligosanthes* Schult. Railroads; 914.
Panicum praecocius Hitchc. & Chase. Dry soil, prairies; M-L.
+*Panicum virgatum* L. Railroads, prairie remnants; frequent; 987.
+*Phalaris arundinacea* *L. Marshes, stream banks; sight record.
**Phleum pratense* L. Old fields, waste places; common; 956.
+*Phragmites communis* Trin. Wet ditches, ponds; infrequent; 1273.
**Poa annua* L. Ditches, moist ground; M-L.
**Poa compressa* L. Old fields, roadsides; M-L.
**Poa pratensis* L. Waste places, open woods; common; 252.

+*Poa sylvestris* Gray. Open woods; 787.
+*Schizachyrium scoparium* (Michx.) Nash. Railroads, dry fields; frequent; 1329.
•*Secale cereale* L. M-L.
•*Setaria faberii* Herrm. Old fields, waste places; common; 1028.
•*Setaria lutescens* (Weigel) Hubb. Old fields, waste places; common; 1099.
•*Setaria verticillata* (L.) Beauv. Old fields, waste places; M-L.
•*Setaria viridis* (L.) Beauv. Old fields, waste places; common; 1066.
Sorghastrum nutans (L.) Nash. Prairies, railroads; frequent; 309
Spartina pectinata Link. Moist ditches; common; 1142.
Sporobolus asper (Michx.) Kunth. Railroads, prairies; Winterringer 12266 (ISM).
+*Stipa spartea* Trin. Sandy soils, prairies; infrequent; 1027.
Tridens flava (L.) Hitchc. Old fields, waste places; common; 1282
+ •*Triticum aestivum* L. Old fields, roadsides; occasional; 264.
+ •*Zea mays* L. Roadsides, railroads; occasional, but not persisting; sight record.

CYPERACEAE

Carex annectens (Bickn.) Bickn. Wet ground, stream banks; 812.
+*Carex artitecta* Mack. Moist woods; 715.
Carex bicknellii Britt. Prairies, dry open woods; 862.
Carex blanda Dewey. Stream banks, woods; 937.
+*Carex brevior* (Dewey) Mack. Moist ground; 823.
+*Carex cephalophora* Muhl. Moist fields, woods; 224.
+*Carex conjuncta* Boott. Moist alluvial woods, fields; 865.
Carex cristatella Britt. Old fields; Koelling 2776 (ISM).
+*Carex davisii* Schw. & Torr. Open alluvial woods; 866.
Carex emoryi Dewey. M-L.
+*Carex festucacea* Schk. Wet ground; 775.
Carex frankii Kunth. Moist fields; Koelling 2778 (ISM).
+*Carex granularis* Muhl. Moist fields, alluvial woods; 764.
Carex gravida Bailey. Moist fields, ditches; 788.
Carex grisea Wahl. Moist alluvial soils; 792.
+*Carex hystricina* Muhl. Moist banks; 852.
+*Carex leavenworthii* Dewey. Old fields, yards; 726.
+*Carex lupulina* Muhl. Moist fields; Weik B44 (LFC).
Carex lurida Wahl. Wet woods; M-L.
+*Carex normalis* Mack. Moist fields, alluvial soils; 201.
Carex pensylvanica Lam. Woodland stream banks; 447.
+*Carex rosea* Schk. Upland woods; 752.
Carex scoparia Schk. Moist fields, stream banks; Weik B121 (LFC).
+*Carex stipata* Muhl. Wet ground; 723.
+*Carex tribuloides* Wahl. Wet, marshy ground; 822.
Carex trichocarpa Muhl. M-L.
Carex vesicaria L. Marshes; Weik B56 (LFC).
Carex vulpinoides Michx. Moist fields, ditches; 825.
Cyperus esculentus L. Old fields, roadsides; 1137.
Cyperus strigosus L. Wet banks of ponds, streams;298.
+*Eleocharis erythropoda* Steud. Shallow ponds, marshes; 811.
+*Eleocharis obtusa* (Willd.) Schult. Marshy ground; Weik B72 (LFC).
+*Eleocharis ovata* (Roth) R. & S. Shallow ponds, marshes; 295.
Eleocharis palustris (L.) Roem. & Schult. Shallow ponds, marshes; Weik B52 (LFC).
+*Scirpus acutus* Muhl. Shallow ponds, marshes, frequent; 810.
Scirpus atrovirens Willd. Shallow ponds, marshes, sandy soil; 853.

+*Scirpus cyperinus* (L.) Kunth. Marshy ground; sight record.
Scirpus pendulus Muhl. Shallow ponds, marshes; common; 813.
Scirpus validus Vahl. Shallow ponds, marshes; Weik B75 (LFC).

ARACEAE

+*Arisaema dracontium* (L.) Schott. Moist field; Weik B81 (LFC).
Arisaema triphyllum (L.) Schott. Upland woods; frequent; 21.
+*Symplocarpus foetidus* (L.) Nutt. Wet stream bank; rare; sight record.

LEMNACEAE

Lemna gibba L. Quiet water; M-L.
Lemna minor L. Quiet water, ponds, marshes; common; 523.
Lemna trisulca L. Quiet water, ponds, marshes; frequent; 884.
Spirodela polyrhiza (L.) Schleiden. Quiet water; Weik B137 (LFC).
Wolffia columbiana Karst. Quiet water, ponds; Weik B110 (LFC).

COMMELINACEAE

+ **Commelina communis* L. Moist woods, old fields; common; 1119.
Tradescantia ohiensis Raf. Woods, thickets; common; 61.

JUNCACEAE

Juncus dudleyi Wieg. Wet banks of streams, ponds; common; 258.
Juncus interior Wieg. Wet ditches, banks; common; 808.
Juncus tenuis. Willd. Moist fields, ditches; common; 763.
Juncus torreyi Coville. Wet ditches, banks; infrequent; 1025.

LILIACEAE

Allium canadense L. Upland woods; common; 782.
Allium tricoccum Ait. Upland woods; infrequent; 1212.
**Allium vineale* L. Old fields, waste places; frequent; 975.
+ **Asparagus officinalis* L. Old fields, waste places; frequent; 67.
Camassia scilloides (Raf.) Cory. Prairie remnant; very rare; sight record.
Erythronium albidum Nutt. Alluvial woods; common; Nichols 29.
+ **Hemerocallis fulva* L. Roadsides, waste places; frequent; 502.
+*Lilium michiganense* Farw. Prairie remnants; rare; 984.
Melianthium virginicum L. Moist woods; rare; M-L.
Polygonatum commutatum (Schult.) A. Dietr. Woods, roadsides; common; 803.
Smilacina racemosa (L.) Desf. Upland woods; common; 758.
+*Smilacina stellata* (l.) Desf. Upland woods; sight record.
Trillium flexipes Raf. Rich woods; rare; Hoopes 26.
Trillium grandiflorum (Michx.) Salisb. M-L.
Trillium nivale Riddell. Woods, north slopes; infrequent; 1.
Trillium recurvatum Beck. Upland woods; common; 6.
Uvularia grandiflora Sm. Upland woods; frequent; 784.

SMILACACEAE

Smilax ecirrata (Engelm.) S. Wats. M-L.
Smilax herbacea L. Woods, thickets; frequent; 503.
Smilax hispida Muhl. Woods; frequent; 929.

DIOSCOREACEAE

Dioscorea villosa L. Margins of woods, thickets; common; 494.

AMARYLLIDACEAE

Hypoxis hirsuta (L.) Cov. Dry woods, praires; infrequent; Murphy 51.

IRIDACEAE

+*Iris shrevei* Small. Marshes, moist banks; Weik B46 (LFC).
Sisyrinchium albidum Raf. Dry open woods, prairies; 28.
Sisyrinchium campestre Bickn. Dry open woods, prairies; 801.

ORCHIDACEAE

Cypripedium reginae Walt. M-L.
Habenaria leucophaea (Nutt.) Gray. Wet prairies; M-L.
Liparis liliifolia (L.) Rich. Open woods; infrequent; 796.
Orchis spectabilis L. Upland woods; rare; Talbot 919.
+*Spiranthes ovalis* Lindl. Open woods, thickets; rare; Ward s.n.

SALICACEAE

Populus deltoides Marsh. Old fields, thickets; common; 439.
Populus grandidentata Michx. Woods; infrequent; Winterringer 11276 (ISM).
+*Populus tremuloides* Michx. Dry hillsides, woods; infrequent; 1209.
+*Salix amygdaloides* Anderss. Open stream banks, lakes; 709.
Salix candida Flugge. Open stream bank; M-L.
+*Salix humilis* Marsh. Prairie remnant; rare; 1018.
Salix interior Rowlee. Shallow ponds streams; common; 771.
Salix nigra L. Stream, pond, lake banks; common; 711.
+*Salix rigida* Muhl. Stream, pond, lake banks; frequent; 440.

JUGLANDACEAE

Carya cordiformis (Wang.) K. Koch. Upland woods; common; 891
Carya ovata (Mill.) K. Koch. Upland woods; common; 733.
Carya tomentosa (Poir.) Nutt. Upland woods; 1355.
Juglans cinerea L. Upland woods; rare; sight record.
+*Juglans nigra* L. Upland and alluvial woods; frequent; 789.

BETULACEAE

Corylus americana Walt. Upland woods; common; 431.
Ostrya virginiana (Mill.) K. Koch. Upland woods; common; 751.

FAGACEAE

Quercus alba L. Upland woods; common; 470.
Quercus imbricaria Michx. Upland and alluvial woods; frequent; 473.

Quercus macrocarpa Michx. Alluvial woods and dry upland woods; frequent; 786.
Quercus marilandica Muench. Dry upland woods; Winterringer 11234 (ISM).
Quercus muhlenbergii Engelm. Calcareous soils; M-L.
Quercus rubra L. Upland woods, north slopes; common; 461.
Quercus velutina Lam. Upland woods; common; 469.

ULMACEAE

Celtis occidentalis L. Open woods, thickets; common; 965.
Ulmus americana L. Secondary woods, stream banks; common; 999.
+ **Ulmus pumila* L. Railroads, waste places; frequent; 1171.
Ulmus rubra Muhl. Secondary woods, stream banks; common; 430.

CANNABINACEAE

Cannabis sativa L. Old fields, waste places; frequent; 1031.
+ **Humulus japonicus* Sieb. & Zucc. Waste places; infrequent; 1201.
Humulus lupulus L. Thickets, waste places; frequent; 1159.

MORACEAE

**Maclura pomifera* (Raf.) Schneid. Thickets, fence rows; common; 897.
**Morus alba* L. Secondary woods, thickets; infrequent escape; 488.
Morus rubra L. M-L.

URTICACEAE

+*Boehmeria cylindrica* (L.) Sw. Marshes; 1185.
Laportea canadensis (L) Wedd. Alluvial woods; common, Ward 1966.
Parietaria pensylvanica Muhl. Upland woods, waste places; common; 900.
Pilea pumila (L.) Gray. Moist aluvial soils, woods; common; 1217.
Urtica dioica L. Moist fields, waste places; common; 522.

SANTALACEAE

+*Comandra richardsiana* Fern. Dry bluff, prairie remnant; rare; 807.

ARISTOLOCHIACEAE

Asarum canadense L. Rich woods; frequent; 20.

POLYGONACEAE

Polygonum aviculare L. Roadsides, old fields; common; 1110.
Polygonum coccineum Muhl. Marshy ground, ditches; Winterringer 13074 (ISM).
**Polygonum convolvulus* L. Old fields, thickets; common; 1105.
**Polygonum cuspidatum* Sieb. & Zucc. Infrequent garden escape; M-L.
+*Polygonum hydropiperoides* Michx. Marshes, wet ground; 1190.
Polygonum lapathifolium L. Marshes, wet ground; 1275.
Polygonum pensylvanicum L. Old fields, ditches; common; 1103.
**Polygonum persicaria* L. Old fields, waste places; common; 800.
Polygonum punctatum Ell. Marshes, wet woods; common; 1180.
Polygonum sagittatum L. Marshes; 1179.
Polygonum scandens L. Alluvial soil; frequent; 293.
Polygonum virginianum L. Upland woods; common; 1197.

Rumex acetosella L. Old fields, waste places; common; 222.
Rumex altissimus Wood. Old fields, roadsides; 519.
**Rumex crispus* L. Old fields, roadsides; common; 482.
+*Rumex verticillatus* L. Marshes; 1187.

CHENOPODIACEAE

Atriplex patula L. Waste places, old fields; sight record.
Chenopodium album L. Old fields, waste places; common; 1352.
+*Chenopodium hybridum* L. Roadside thicket; 1095.
**Kochia scoparia* (L.) Schrader. Waste places, old fields; common; 1351.

AMARANTHACEAE

Amaranthus albus L. Old fields, waste places; M-L.
**Amaranthus retroflexus* L. Old fields, waste places; common; 1138.
**Amaranthus hybridus* L. M-L.

NYCTAGINACEAE

Mirabilis nyctaginea (Michx.) MacM. Railroads, gravelly soil; 911.

PHYTOLACCACEAE

+*Phytolacca americana* L. Old fields, thickets; common; 1048.

MOLLUGINACEAE

Mollugo verticillata L. Waste places, yards; common; 1127.

PORTULACACEAE

Claytonia virginica L. Upland woods; common; 4.
**Portulaca oleracea* L. Waste places, yards, common; sight record.

CARYOPHYLLACEAE

+*Arenaria lateriflora* L. Open woods; Nichols 58.
Cerastium nutans Raf. Moist fields, roadsides; common; 716.
**Cerastium vulgatum* L. Waste places, old fields; common; 205.
+ **Dianthus armeria* L. Dry fields, open woods; frequent; 229.
+ **Lychnis alba* Mill. Old fields, thickets; common; 1168.
**Saponaria officinalis* L. Railroads, waste places; common; Fach 237 (ISM).
Silene antirrhina L. Railroad; Winterringer 18111 (ISM).
+*Silene nivea* (Nutt.) Otth. Thickets, alluvial soil; 873.
Silene stellata (L.) Ait. Old fields, thickets; 1059.
**Stellaria media* (L.) Vill. Waste places, yards; common; 35.

CERATOPHYLLACEAE

Ceratophyllum demersum L. Quiet water, shallow ponds; common; 742.

NYMPHACEAE

+*Nymphaea tuberosa* Paine. Quiet water, shallow ponds; infrequent; 814.

RANUNCULACEAE

Actea alba (L.) Mill. Upland woods; infrequent; 783.
+*Anemone canadensis* L. Open woods, thickets; frequent; 962.
Anemone virginiana L. Upland woods; common; 506.
Aquilegia canadensis L. Calcareous soils, woods; rare; Fach 91 (ISM).
Caltha palustris L. Quiet water, streams, ponds; Fach 8 (ISM).
Clematis pitcheri T. & G. M-L.
Clematis virginiana L. Thickets, fence rows; infrequent; 1158.
+*Delphinium carolinianum* Walt. Railroad; Van Ness 96.
Delphinium tricorne Michx. Old fields, roadsides; frequent; Fach 116 (ISM).
Hepatica acutiloba DC. Upland woods, north slopes; common; 2.
Isopyrum biternatum (Raf.) T. & G. Upland woods; infrequent; 720.
Ranunculus abortivus L. Open woods, old fields; common; 56.
+*Ranunculus aquatilis* L. Quiet water, shallow ponds; infrequent; 236.
Ranunculus fascicularis Muhl. Moist open woods; Fach 3 (ISM).
+*Ranunculus flabellaris* Raf. Quiet water; Weik B60 (LFC).
+*Ranunculus recurvatus* Poir. Alluvial woods; frequent; 794.
Ranunculus septentrionalis Poir. Moist woods; common; 23
+*Thalictrum dasycarpum* Fisch. & Ave-Lall. Moist old fields, thickets; common; 245.
Thalictrum revolutum DC. Old fields, roadsides; 855.

BERBERIADACEAE

+ **Berberis thunbergii* DC. Open woods; occasional escape; 467.
Caulophyllum thalictroides (L.) Michx. Upland woods; infrequent; 1213.
Podophyllum peltatum L. Upland woods; common; 887.

MENISPERMACEAE

Menispermum canadense L. Upland woods; frequent; 1333.

PAPAVERACEAE

+ **Papaver rhoeas* L. Railroads; infrequent escape; Van Ness 92.
Sanguinaria canadensis L. Upland woods; frequent; Saunders 1.

FUMARIACEAE

+*Corydalis micrantha* (Engelm.) Gray. Railroads; Reiners 22.
Dicentra cucullaria (L.) Bernh. Upland woods; frequent; 3.

CRUCIFERAE

Arabis canadensis L. Woods; M-L.
**Barbarea vulgaris* R. Br. Old fields, waste places; common; 730.
**Brassica juncea* (L.) Cosson. Old fields, waste places; M-L.
**Brassica nigra* (L.) Koch. Old fields, waste places; sight record.
Capsella bursa-pastoris (L.) Medic. Waste places, yards; common; 32.
+*Cardamine pensylvanica* Muhl. Marshes, alluvial soils; 1302.
**Cardaria draba* (L.) Desv. Waste places; Liston 27.
Dentaria laciniata Muhl. Upland woods; frequent; 5.
Descuranis prinnate (Wait.) Britt. Old fields, railroads; Fach 94 (ISM).
+ **Descurainia sophia* (L.) Webb. Railroads; 708.
**Lepidium campestre* (L.) R. Br. Waste places, yards; common; 817.

Lepidium densiflorum Schrader. Old fields, waste places; common; 250.
Lepidium virginicum L. Old fields, roadside; common; 737.
+ **Nasturtium officinale* R. Br. Small springs in open woods; rare; sight record.
+*Rorippa islandica* (Oeder) Borbas. Old fields, waste areas; common; 882.
**Sisymbrium altissimum.* L. Old fields, waste places; M-L.
**Sisymbrim loeselii* L. Old fields, waste places; M-L.
**Sisymbrium officinale* (L.) Scop. var. *leiocarpum* DC. Old fields, waste places; 739.
**Thlaspi arvense.* L. Old fields, waste places; common; Fach 95 (ISM).

CAPPARIDACEAE

+*Polanisia dodecandra* (L.) DC. Dry waste places, railroads; frequent; 972.

CRASSULACEAE

Penthorum sedoides L. Marshes; 1184.

SAXIFRAGACEAE

Heuchera richardsonii R. Br. Dry fields, prairies; infrequent; 959.
Ribes missouriense Nutt. Upland woods; common; 450.
+ **Ribes sativum* Syme. Fence row; infrequent escape; 713.

PLATANACEAE

Platanus occidentalis L. Alluvial woods; common; sight record.

ROSACEAE

Agrimonia gryposepala Wallr. Upland woods; frequent; Ward 2028.
+*Agrimonia parviflora* Ait. Marshes, moist woods; 1188.
Agrimonia pubescens Wallr. Upland woods; frequent; 1040.
Agrimonia rostellata Wallr. M-L.
+*Amelanchier arborea* (Michx. f.) Fern. Calcareous soils; rare; Parmenter 19.
Aruncus dioicus (Walt.) Fern. Upland woods; infrequent; 797.
+*Crataegus calpodendron* (Ehrh.) Medic. Thickets; Bischoff 49.
+*Crataegus crus-galli* L. Thickets, forest margins; sight record.
Crataegus mollis (T. & G.) Scheele. Thickets, forest margins; 464.
Crataegus punctata Jacq. Thickets, forest margins; M-L.
Crataegus succulenta Link. Thickets, forest margins; M-L.
Fragaria virginiana Duch. Old fields, open woods; common; 13.
Geum canadense Jacq. Thickets, open woods; frequent; 907.
+*Geum laciniatum* Murr. Wet ditches, wet thickets; 981.
Malus ioensis (Wood) Britt. Thickets, secondary woods; common; Lawton 16.
Physocarpus opulifolius (L.) Maxim. Stream banks; M-L.
Potentilla arguta Pursh. Dry open woods, prairies; M-L.
Potentilla norvegica L. Old fields, thickets; common; 263.
**Potentilla recta* L. Old fields, thickets; common; 216.
Potentilla simplex Michx. Old fields, open woods; common; 226.
Prunus americana var. Marsh. *americana.* Thickets, open woods; common; 453.
+*Prunus americana* Marsh. var. *lanata* Sudw. Thickets, open woods; common; 454.
Prunus nigra Ait. Open woods; M-L.
Prunus serotina Ehrh. Upland woods, thickets, common; Springer 29.
Prunus virginiana L. Upland woods; frequent; 714.

Rosa carolina L. Old fields, prairies; frequent; 254.
+ **Rosa multiflora* Thunb. Old fields, thickets; common; 480.
+*Rosa setigera* Michx. var. *tomentosa* T. & G. Moist field; Weik B86 (LFC).
Rubus allegheniensis Porter. Thickets, open woods; common; Springer 41.
Rubus argutus Link. Open woods, thickets; Bischoff 47.
+*Rubus occidentalis* L. Thickets, open woods; common; 942.

CESALPINIACEAE

Cassia fasciculata Michx. Old fields, roadsides; common; 1037.
Cercis canadensis L. River and larger stream valleys; frequent; sight record.
Gleditsia triacanthos L. Alluvial woods and slopes above major streams; common; 904.

FABACEAE

Amorpha canescens Pursh. Prairies; rare; 1014.
+*Amphicarpa bracteata* (L.) Fern. Aluvial woods; common; 292.
Apios americana Medic. Alluvial woods; common; 501.
Astragalus canadensis L. Old fields, railroads; frequent; 1034.
Baptisia leucantha T. & G. Old fields, open woods; Koelling 2768 (ISM).
+*Baptisia leucophaea* Nutt. Dry bluff, prairie remnant; very rare; sight record.
+ **Coronilla varia* L. Roadsides; frequent; 961.
Desmodium canadense (L.) DC. Prairies, railroads; infrequent; 1011.
+*Desmodium cuspidatum* (Muhl.) Loud. Upland woods; frequent; 1106.
Desmodium dillenii Darl. M-L.
Desmodium glutinosum (Muhl.) Loud. Upland woods; common; 1060.
Desmodium illinoense Gray. Prairies, railroads; infrequent; 1026.
Lespedeza capitata Michx. Prairies, dry woods; M-L.
Lespedeza violacea. (L.) Pers. Dry woods; M-L.
+*Lespedeza virginica* (L.) Britt. Old fields; Ward 1976.
+ **Lotus corniculatus* L. Roadsides, waste places; common; 902.
**Medicago lupulina* L. Old fields, roadsides; common; 228.
**Medicago sativa* L. Old fields, roadsides; common; 248.
**Melilotus alba* Desr. Old fields, roadsides; common; 262.
**Melilotus officinalis* (L.) Desr. Old fields, roadsides; common; 233.
+*Petalostemum candidum* (Willd.) Michx. Prairies; rare; 1074.
Petalostemum purpureum (Vent.) Rydb. Prairies; rare; 1008.
**Robinia pseudoacacia* L. Secondary woods; frequent; Springer 39.
Strophostyles helveola (L.) Ell. Railroads; 1115.
**Trifiolium hybridum* L. Old fields, roadsides; Fach 134 (ISM).
**Trifolium pratense* L. Old fields, roadsides; common; 231.
+ **Trifolium procumbens* L. Old fields, roadsides; common; 943.
**Trifolium repens* L. Old fields, roadsides; common; 232.
**Vicia villosa* Roth. M-L.

OXALIDACEAE

Oxalis dillenii Jacq. Old fields, open woods; common; 251.
Oxalis stricta L. Old fields, open woods; common 217.
Oxalis violacea L. Open woods, prairies, frequent; Wolf 33.

GERANIACEAE

Geranium carolinianum L. Fields, roadsides; M-L.
Geranium maculatum L. Upland woods; frequent; 26.

RUTACEAE

Ptelea trifoliata L. Thickets, margins of woods; infrequent; 768.

SIMAROUBACEAE

+ **Ailantus altissima* (Mill.) Swingle. Waste places, yards; common; sight record.

POLYGALACEAE

+*Polygala sanguinea* L. Dry fallow fields; infrequent; 283.
Polygala verticillata L. Moist woods, prairies; M-L.

EUPHORBIACEAE

Acalypha rhomboidea Raf. Open moist woods; Winterringer 11286 (ISM).
+*Croton glandulosus* L. Waste places, railroads; 1202.
Euphorbia corollata L. Dry bluffs, prairies; frequent; 912.
+ **Euphorbia cyparissias* L. Old fields, roadsides; infrequent escape; 895.
Euphorbia dentata Michx. Waste places, railroads; 1308.
+ **Euphorbia esula* L. Railroads; Baker 88.
Euphorbia maculata L. Old fields, waste places; common; 329.
Euphorbia supina Raf. M-L.

LIMNANTHACEAE

+*Floerkea proserpinacoides* Willd. Upland woods; 721.

ANACARDIACEAE

Rhus glabra L. Old fields, thickets; common; 277.
Toxicodendron radicans (L.) Kuntze. Thickets, woods; common; 781.

CELASTRACEAE

+*Celastrus scandens* L. Upland woods; frequent; 303
Euonymus atropurpureus Jacq. Thickets, margin of woods; 1029.

STAPHYLEACEAE

Staphylea trifolia L. Upland woods, north slopes; frequent; 1339.

ACERACEAE

Acer negundo L. Secondary woods, old fields; common; 438.
Acer saccharinum L. Alluvial woods, old fields; common; 432.
Acer saccharum Marsh. Upland woods, north slopes; common; 760.

HIPPOCASTANACEAE

Aesculus glabra Willd. Alluvial woods; infrequent; Woodworth 15.

BALSAMINACEAE

+*Impatens biflora* Walt. Moist alluvial woods; common; 1160.
Impatens pallida Nutt. Moist alluvial woods; common; 291.

RHAMNACEAE

Ceanothus americanus L. Prairies, thickets; infrequent; 1153.
Rhamnus lanceolata Pursh. Open woods; Winterringer 11277 (ISM).

VITACEAE

Parthenocissus quinquefolia (L.) Planch. Upland woods, thickets; common; 767
+*Parthenocissus vitacea* (Knerr) Hitchc. Wet woods, marshes; 1189.
Vitis riparia Michx. Old fields, thickets; frequent; 735.

TILIACEAE

Tilia americana L. Upland woods, north slopes; common; 793.

MALVACEAE

**Abutilon theophrasti* Medic. Old fields, waste places; common; Ward 1969.
+ **Althea rosea* L. Old fields; infrequent escape; 517.
Callirhoe triangulata (Leavenw.) Gray. Dry sand prairies; rare; M-L.
**Hibiscus trionum* L. Old fields, waste places; common; 1104.
+ **Malva neglecta* Wallr. Old fields, waste places; occasional; 1204.
Napaea dioica L. Moist ditches, railroad; infrequent; 976.
+*Sida spinosa* L. Old fields, waste places; frequent; 1203.

HYPERICACEAE

**Hypericum perforatum* L. Old fields, roadsides; frequent; 255.
Hypericum punctatum Lam. Old fields, thickest; infrequrnt; 1058.
Hypericum pyramidatum Ait. Thickets, margins of woods; 273.

CISTACEAE

Helianthemum bicknellii Fern. Dry sandy soil; M-L.

VIOLACEAE

Viola eriocarpa Schw. Upland woods; common; 8.
Viola fimbiatula Sm. Dry fields; M-L.
Viola papilionacea Pursh. Upland woods; common; 9.
Viola pedata L. Prairies, open woods; frequent; 27.
+*Viola pedatifida* G. Don. Prairies; rare; sight record.
Viola sagittata Ait. Old fields; 29.
Viola sororia Willd. Upland woods; common; Barker 8.

LYTHRACEAE

Lythrum alatum Pursh. Sandy stream banks; frequent; 997.
+*Peplis diandra* Nutt. Shallow ponds, lakes; Weik B73 (LFC).

ONAGRACEAE

Circea quadrisulcata (Maxim.) Franch. & Sav. Upland woods; common; 511.
+*Epilobium coloratum* Biehler. Marshes, wet ground; sight record.
Gaura biennis L. Old fields, railroads; frequent; 312.
Gaura parviflora Dougl. Railroads; 1086.
Oenothera biennis L. Old fields, waste places; common; 1047.

HALORAGIDACEAE

Myriophyllum spicatum L. var. *exalbescens* (Fern.) Jeps. Quiet water, ponds,lakes; common; 827.

ARALIACEAE

+*Aralia nudicaulis* L. Upland Woods; sight record.
+*Panax quinquefolius* L. Rich woods, north slopes; rare; 290.

UMBELLIFERAE

+ **Aethusa cynapium* L. Rare escape; Derge 67.
+*Chaerophyllum procumbens (L.) Crantz. Upland woods; frequent; 19.*
Cicuta malculata L. Marshes, wet ditches; frequent; 998.
Cryptotaenia canadensis (L.) DC. Moist woods; common; 485.
**Daucus carota* L. Old fields, waste places; 1166.
Eryngium yuccifolium Michx. Prairies, dry open woods; infrequent; 271.
Heracleum maximum Bartr. Marshes, wet ground; sight record.
Osmorhiza longistylis (Torr.) DC. Upland woods; common; 212.
**Pastinaca sativa* L. Old fields, waste places; common; 239.
Sanicula canadensis L. Upland woods; common; 916.
+*Sanicula gregaria* Bickn. Upland woods; common; 732.
+*Sium suave* Walt. Marshes, wet ground; infrequent; 1191.
Taenidia integerrima (L.) Drude. Dry woods; M-L.
+*Thaspium barbinode* (Michx.) Nutt. Moist woods; frequent; 218.
+*Zizia aurea* (L.) Koch. Moist fields; 63.

CORNACEAE

+*Cornus obliqua* Raf. Upland woods; 1123.
Cornus racemosa Lam. Thickets, margins of woods; common; 204.

ERICACEAE

+*Monotropa uniflora* L. Upland woods; rare; 282.

PRIMULACEAE

Lysimachia ciliata L. Moist fields, ditches; common; 966.
+*Lysimachia hybrida* Michx. Marshes; 1146.
+ **Lysimachia nummularia* L. Open stream bankss, pastures; 1194

OLEACEAE

Fraxinus americana L. Alluvial and upland woods; common; 944.
Fraxinus quadrangulata Michx. Alluvial woods; rare; M-L.
+ **Ligustrum vulgare* L. Roadside; rare escape; sight record.

GENTIANACEAE

+*Gentiana andrewsii* Griseb. Prairies; rare; sight record.
+*Gentiana puberula* Michx. Prairies; very rare; sight record.

APOCYNACEAE

Apocynum androsaemifolium L. Old fields, thickets; Ward 1895.
Apocynum cannabinum L. Old fields, dry open woods; common; 238.
Apocynum sibiricum Jacq. M-L.

ASCLEPIADACEAE

Asclepias hirtells (Pennell) Woodson. Dry prairies. rare; M-L.
Asclepias incarnata L. Marshes, wet ground; frequent; 1177.
+*Asclepias purpurascens* L. Old fields; infrequent; 225.

Asclepias quadrifolia Jacq. Upland woods; infrequent; 749
Asclepias sullivantii Engelm. Wet prairies; rare; M-L.
Asclepias syriaca L. Old fields, waste places; common; 265.
+*Asclepias tuberosa* L. Fence row along cemetery; rare; Ward 2040.
Asclepias verticillata L. Old fields, waste places; common; 275.

CONVOLVULACEAE

Calystegia sepium (L.) R. Br. var. *americana* (Sims.) Mohlenb. Old fields, waste places; common; 266.
+*Calystegia spithamaea* (L.) Pursh. Open dry woods; Ward 1832.
**Convolvulus arvensis* L. Roadsides, waste places; common; 974.
Ipomoea pandurata (L.) Gfw. Meyer. Fence rows, waste places; frequent; 1114.

POLEMONIACEAE

+ **Gilia rubra* (L.) Heller. Wet ditch; sight record.
Phlox divaricata L. Upland woods; common; 14.
Phlox glaberrima L. Dry woods, prairies; M-L.
Phlox paniculata L. Upland woods; M-L.
+*Phlox pilosa* L. Dry prairies; rare; 809.
Polemonium reptans Open woods; sight record.

HYDROPHYLLACEAE

+*Ellisia nyctelea* L. Alluvial, wet woods; common; 790.
+*Hydrophyllum appendiculatum* Michx. Rich woods; 58.
Hydrophyllum virginianum L. Stream banks in upland woods; common; 57.

BORAGINACEAE

**Cynoglossum officinale* L. Waste places; M-L.
Hackelia virginiana (L.) Johnst. Alluvial and upland woods; common; 1083.
**Lappula echinata* Gilib. Thickets, open woods; sight record.
Lithospermum canescens (Michx.) Lehm. Prairies; rare; 898.
+*Lithospermum incisum* Lehm. Dry fields; Wilson s.n.
Mertensia virginica (L.) Pers. Upland woods; common; 15.
+ **Symphytum officinale* L. Roadside; Baker 93.

VERBENACEAE

+*Lippia lanceolata* Michx. Wet banks; frequent; 1195.
Verbena bracteata Lag.& Rodr. Roadsides, waste places; 1111.
Verbena hastata L. Old fields, roadsides; 1079.
Verbena stricta Vent. Old fields, waste places; common; 274.
Verbena urticifolia L. Old fields, waste places; common; 1022.

LABIATAE

Agastache nepetoides (L.) Kuntze. Old fields, thickets; 1077.
Agastache scrophulariaefolia (Willd.) Kuntze. Open woods; Winterringer 11272 (ISM).
Blephilia hirsuta (Pursh) Benth. Moist woods; M-L.
+ **Glecoma hederacea* L. Waste places, yards; common; 11.
+*Hedeoma hispida* Pursh. Railroad; sight record.
Hedeoma pulegioides (L.) Pers. Woods; Winterringer 11360 (ISM).
+ **Lamium amplexicaule* L. Waste places, yards; Van Ness 44.
+ **Leonurus cardiaca* L. Moist fields, thickets; frequent; 493.

Lycopus americanus Muhl. Marshes, ditches; common; 118.
Lycopus rubellus Moench. Marshes; M.L.
Lycopus virginicus L. Marshes, ditches; 296.
+*Mentha arvensis* L. Wet ditches; 1126.
**Mentha spicata* L. Wet ditches, stream banks; M.L.
Monarda fistulosa L. Old fields, waste places; common; 1013.
**Nepeta cataria* L. Roadside; 971.
+*Prunella vulgaris* L. Open woods, waste places; 1006.
Pycnanthemum pilosum Nutt. Dry fields, prairies; infrequent; 1152.
Pycnanthemum tenuifolium Schrad. Dry fields, prairies; common; 273.
Pycnanthemum virginianum (L.) Durand & Jackson. Prairies; infrequent; 1009.
+ **Salvia pitcheri* Torr. Dry fields; infrequent; 313.
Scutellaria lateriflora L. Marshes, wet banks; 300.
+*Scutellaria ovata* Hill. Upland woods; frequent; 948.
Stachys palustris L. var. *homotricha* Fern. Moist fields; Weik B88 (LFC).
+*Stachys tenuifolia* Willd. var. *hispida* (Pursh) Fern. Railroad; 1170.
Teucrium canadensis L. Upland woods; common; 1007.

SOLANACEAE

+ **Datura stramonium* L. Waste places, fields; common 1135.
Physalis heterophylla Nees. Old fields, roadsides; Koelling 2769 (ISM).
+*Physalis longifolia* Nutt. Old fields, roadsides; 1033.
Physalis pubescens L. Old fields, roadsides; 1061.
Physalis subglabrata Mack. & Bush. Waste places; 1093.
Physalis virginiana Mill. Old fields; M-L.
Solanum carolinense L. Old fields, waste places; common; 513.
Solanum americanum Mill. Old fields, waste places; common; 1092.
+ **Solanum dulcamara* L. Waste places, thickets; frequent; 55.

SCROPHULARIACEAE

+*Castilleja coccinea* L. Spreng. Dry hillsides, prairies; rare; Brown 29.
**Chaenorrhinum minus* (L.) Lange. Railroads; 809.
+*Gerardia gattingeri* Sm. Open woods; Ward 1975.
Gerardia grandiflora Benth. Upland woods; M-L.
Gerardia tenuifolia Vahl. Open woods; M-L.
**Linaria vulgaris* Hill. Roadsides; infrequent escape; 1134.
+*Lindernia anagallidea* (Michx.) Pennell. Banks of shallow ponds, marshes; 1144.
Lindernia dubia (L.) Pennell. Stream bank; M-L.
Mimulus ringens L. Marshes, wet ditches; 1108.
+*Pedicularis canadensis* L. Woods, prairies; infrequent; 791.
+*Penstemon digitalis* Nutt. Dry roadside; 856.
+*Penstemon pallidus* Small. Dry railroad; Thraikill s.n.
Scrophularia marilandica L. Alluvial woods; thickets; 1063.
Verbascum blattaria L. M-L.
**Verbascum thapsus* L. Waste places, old fields; common; 1000.
**Veronica arvensis* L. Old fields, waste places, common; 463.
Veronica peregrina L. Old fields, waste places; common; 717.
Veronicastrum virginicum (L.) Farw. Moist prairies; infrequent; 1012.

BIGNONIACEAE

+*Campsis radicans* (L.) Seem. Roadsides, thickets; infrequent; 1165.
+ **Catalpa speciosa* Warder. Stream bank; occasional; sight record.

OROBANCHACEAE

+*Orobanche uniflora* L. Upland woods; rare; Ward 1833.

ACANTHACEAE

Justicia americana (L.) Vahl. Shallow ponds, lakes; Russell s.n. (ISM).
Ruellia humilis Nutt. Old fields, roadsides; frequent; 267.

PHRYMACEAE

Phryma leptostachya L. Upland woods; frequent; 1062.

PLANTAGINACEAE

Plantago aristata Michx. Dry sandy soil; 1032.
**Plantago lanceolata* L. Old fields, waste places; common; 230.
Plantago rugelii Decne. Old fields, waste places, yards; common; 520.
+*Plantago virginica* L. Dry fields; 778.

RUBIACEAE

Galium aparine L. Old fields, woods; common; 719.
Galium circaezans Michx. Upland woods; common; 785.
Galium concinnum T. & G. Upland woods; common; 211.
Galium obtusum Bigel. Moist woods; M-L.
+*Galium tinctorium* L. Wet ground, thickets; Weik B111 (LFC).
+*Galium trifidum* L. Marshes, wet ground; 1178.
Galium triflorum Michx. Upland woods; common; 512.
Houstonia minima Beck. Dry hillside; M-L.

CAPRIFOLIACEAE

+ **Lonicera* x *bella* Zabel. Open thickets, stream banks; occasional; 995.
Lonicera prolifera (Kirchner) Rehder. Thickets, roadsides; 989.
+ **Lonicera tatarica* L. Thickets, open woods; frequent; Weichert 7.
Sambucus canadensis L. Thickets, stream banks; frequent; 508.
+*Symphoricarpos occidentalis* Hook. Roadsides, thickets; 1356.
Symphoricarpos orbiculatus Moench. Dry woods; M-L.
Triosteum aurantiacum Bickn. M-L.
Triosteum illinoense (Wieg.) Rydb. M-L.
Triosteum perfoliatum L. Upland woods; 871.
Viburnum lentago L. Thickets; Weik B64 (LFC).
+*Viburnum opulus* L. Thickets, stream banks; 710.
Viburnum prunifolium L. Thickets; sight record.

DIPSACACEAE

+ **Dipsacus sylvestris* Hnds. Roadside ditch; sight record.

CAMPANULACEAE

+*Campanula americana* L. Open woods, thickets; common; 525.
Lobelia inflata L. Dry fields, open woods; frequent; 1078.
Lobelia sphilitica L. Marshes, wet ground; frequent; 1288.
Lobelia spicata Lam. Dry fields, open woods; frequent; 967.
+*Specularia perfoliata* (L.) DC. Dry fields, waste places; common; 243.

COMPOSITAE

Achillea millefolium L. Old fields, waste places; common; 68.
Ambrosia artemisiifolia L. Old fields, waste places; common; 1281.
Ambrosia trifida L. Old fields, waste places; common; 1169.
Antennaria neglecta Greene. Dry fields, open woods; frequent; 444.
+*Antennaria plantaginifolia* (L.) Richards. Dry fields, open woods; frequent; 460.
+ **Anthemis arvensis* L. Waste places, yards; Nichols 84.
**Anthemis cotula* L. Waste places; 1136.
Arctium lappa L. Old fields, waste places; common; 521.
+ **Arctium minus* Schk. Old fields, waste places; 1010.
**Artemisia annua* L. Old fields; M-L.
Artemisia ludoviciana Nutt. var *gnaphalodes* (Nutt.) T. & G. Dry fields; M-L.
+*Aster azureus* Lindl. Dry prairie; rare; 1321.
+*Aster chasei* G.N. Jones. Upland woods; 1080.
Aster drummondii Lindl. Dry woods; frequent; 1296.
Aster ericoides L. Dry fields, prairies; common; 325.
Aster hesperius Gray. Old fields; 328.
+*Aster laevis* L. Dry prairie; rare; 1322.
Aster lateriflorus (L.) Britt. M-L.
Aster novae-angliae L. Moist fields, ditches; common; 1324.
Aster ontarionis Wieg. M-L.
Aster parviceps (Burgess) Mack. & Bush. Old fields; 1392.
Aster pilosius Willd. Old fields; 1300.
Aster praealtus Poir. Old fields; 330.
+*Aster sagittifolius* Willd. Dry woods, thickets; frequent; 1317.
Aster shortii Lindl. Woods; M-L.
Aster simplex Willd. Old fields; common; 297.
+*Bidens aristosa* L. Moist fields; marshes; common; 1285.
Bidens cernua L. Marshes, wet ground; 1310.
Bidens comosa (Gray) Wieg. M-L.
+*Bidens coronata* (L.) Britt. Stream bank; sight record.
Bidens frondosa L. Moist banks; 299.
Bidens vulgata Greene. Moist fields; 1311.
+*Boltonia asteroides* (L.) L'Her. Marshes, wet ground; 1304.
Cacalia atriplicifolia L. Moist open woods; Winterringer 2378 (ISM).
**Carduus nutans* L. Old fields, waste places; sight record.
+ **Chrysanthemum leucanthemum* L. Roadsides, cemeteries; 1036.
**Cichorium intybus* L. Old fields, waste places; common; 1133.
Cirsium altissimum (L.) Spreng. Old fields, waste places; M-L.
**Cirsium arvense* (L.) Scop. Old fields, waste places; common; 915.
Cirsium discolor (Muhl.) Spreng. Old fields, waste places; sight record.
Cirsium pumilum (Nutt.) Spreng. Prairies; rare; Jones s.n. (ISM).
**Cirsium vulgare* (Savi) Tenore. Old fields, waste places; common; 308.
Conyza canadensis (L.) Conquist. Old fields, waste places; common; 1231.

Coreopsis palmata Nutt. Prairies, railroads; rare; 940.
Coreopsis tripteris L. Old fields, prairies; frequent; 320.
+*Echinacea pallida* Nutt. Preairies, railroads; infrequent; 910.
Echinacea purpurea (L.) Moench. Open woods; 1216.
Erechtites hieracifolia (L.) Raf. Marshes, wet ground; Winterringer 11281 (ISM).
Erigeron annuus (L.) Pers. Old fields; frequent; 202.
Erigeron philadelphicus L. Old fields, waste places; frequent; 59.
+*Erigeron pulchellus* Michx. Old fields; Ward 1929.
+*Erigeron strigosus* Muhl. Old fields; waste places; frequent; 1043.
Eupatorium altissimum L. Old fields, roadsides; frequent; 307.
Eupatorium perfoliatum L. Marshes, open wet woods; Winterringer 11274 (ISM).
Eupatorium purpureum L. Dry fields, roadsides; frequent; 1084.
Eupatorium rugosum Houtt. Upland woods, thickets; common; 321.
Eupatorium serotinum Michx. Moist fields, ditches; sight record.
+ **Galinsoga ciliata* (Raf.) Blake. Waste places, yards; occasional; 1081.
Gnaphalium obtusifolium L. Dry fields; Ward 1967.
+ **Haplopappus ciliatus* (Nutt.) DC. Dry railroad gravel; 1109.
Helenium autumnale L. Moist fields, roadsides; frequent; 1309.
Helianthus annuus L. Old fields; frequent; 1230.
Helianthus grosseserratus Martens. Old fields; common; 318.
Helianthus occidentalis Riddell. Dry prairies; rare; 1075.
Helianthus petiolaris Nutt. Railroad; sight record.
Helianthus rigidus (Cass.) Desf. Dry prairies; rare; M-L.
Helianthus strumosus L. M-L.
Helianthus tuberosus L. Old fields, railroads; common; 1173.
Heliopsis helianthoides (L.) Sweet. Railroads, prairies; frequent; 986.
+*Heterotheca subaxillaris* (Lam.) Britt. & Rusby. Dry railroad gravel; 1113.
Hieracium longipilum Torr. M-L.
Hieracium scabrum Michx. Open woods; Winterringer 11282 (ISM).
+*Krigia biflora* (Walt.) Blake. Open woods, prairies; infrequent; 524.
Kuhnia eupatorioides L. Old fields, roadsides; Jones s.n.
Lactuca canadensis L. Old fields, waste places; common; 333.
Lactuca floridana (L.) Gaertn. Alluvial woods, moist fields; frequent; 285.
+ **Lactuca saligna* L. Old fields, waste places; 1156.
**Lactuca serriola* L. Roadside; 1155.
+*Liatris aspera* Michx. Dry prairie; rare; 1313.
Liatris pychnostachya Michx. Prairies; M-L.
+ **Matricaria chamomilla* L. Roadsides; 1088.
**Matricaria matricarioides* (Less.) Porter. Old fields, waste places; common; 725.
Prenanthes alba L. Upland woods; 1346.
Prenanthes aspera Michx. Prairies; M-L.
Ratibida pinnata (Vent.) Barnh. Old fields, railroads; frequent; 1019.
Rudbeckia hirta L. Open woods, fields; common; 215.
Rudbeckia laciniata L. Moist woods; Winterringer 11275 (ISM).
Rudbeckia triloba L. Open woods, thickets; frequent; 1082.
+*Senecio pauperculus* Michx. Moist prairies; infrequent; 1035.
+*Senecio plattensis* Nutt. Old fields, roadsides; 65.
Silphium integrifolium Michx. Prairies, railroads; 1020.
Silphium laciniatum L. Prairies, railroads; 1023.
Silphium perfoliatum L. Alluvial banks; common; 1107.
Silphium terebinthinaceum Jacq. Prairies, railroads; 1163.
Solidago canadensis L. Old fields, waste places; common; 306.

Solidago gigantea Ait. Moist fields; M-L.
Solidago graminifolia (L.) Salisb. Marshes, ditches; frequent; 1148.
Solidago juncea Ait. Upland woods; 334.
Solidago missouriensis Nutt. Dry prairie; 1076.
Solidago nemoralis Ait. Old fields, roadsides; common; 1323.
Solidago rigida L. Prairies, railroads; 1316.
Solidago speciosa Nutt. Dry prairie; 1320.
Solidago ulmifolia Muhl. Upland woods; 335.
**Sonchus arvensis* L. var. *glabrescens* Guenth., Gram. & Winn. Old fields, waste places. M-L.
**Sonchus asper* (L.) Hill. Old fields, waste places; common; 1002.
**Sonchus oleraceus* L. Old fields, waste places; common; 1132.
**Taraxacum officinale* Weber. Fields, roadsides; common; 448.
+ **Tragopogon dubius* Scop. Waste places, roadsides; frequent; 753.
**Tragopogon pratensis* L. Waste places, roadsides; frequent; 66.
Verbesina alternifolia (L.) Britt. Alluvial woods; frequent; 287.
+ *Vernonia crinita* Raf. Old fields, open woods; 315.
Vernonia missurica Raf. Dry prairie; 1073.
Xanthium strumarium L. Old fields, waste places; common; sight record.

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DIMENSIONS OF MOLAR TEETH OF *HYPISODUS MINIMUS* (ARTIODACTYLA) FROM THE OLIGOCENE DEPOSITS OF NORTHEASTERN COLORADO

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ABSTRACT

Eighty-five specimens of molar teeth were used to determine variation in size and cusp pattern. These specimens show a small range of variation

INTRODUCTION

Cope (1873) named *Hypisodus minimus* from a fragment of a skull found in the White River formation of northeast Colorado. Galbreath (1953) working in the same area found specimens that prompted him to suggest that a more detailed analysis be made to determine if any significant differences in size and occlusal pattern of the teeth were present that could be correlated with stratigraphic levels.

MATERIALS AND METHODS

Fossil specimens of *Hypisodus minimus* collected by Galbreath between 1951 and 1978, were studied to determine range of variation of the molar teeth. This study was confined to molars due to the scarcity of premolars and other fossil specimens. The bordering bone was removed from the buccal side of the upper molars and from either the buccal or lingual side of the lower molars to expose the crown and roots of each tooth. X-ray examination can be used, but is not as satisfactory.

Eighty-five specimens of upper and lower jaw fragments from the Oligocene (youngest Horsetail Creek, Cedar Creek, and oldest Vista deposits; Galbreath, Fig. 8, 1953) were examined.

The molars of each specimen were measured with a Helios dial caliper to the estimated nearest hundreth of a millimeter. The dimensions measured were anterior-posterior occlusal length (OCL), transverse occlusal width (OCW), greatest anterior-posterior length at the base of the crown (GCL), greatest transverse width at the base of the crown (GCW), and crown height (CH), from occlusal surface to base of enamel.

Range, mean, and standard deviation were determined for each measurement. To determine dimensional changes in the wear patterns, the Pearson Product Moment Correlation (Roscoe, 1975) was calculated and significant results were demonstrated with scattergrams. Each tooth was examined for variations in the cusp pattern as described by Scott (1940) and Galbreath (1953).

RESULTS AND DISCUSSION

The results of this study are summarized in Table 1.

Measurements of the teeth of *Hypisodus* sp. Form A (Galbreath, 1953) fit within the ranges reported here. Galbreath's *Hypisodus* sp. Form B was described as approaching the size of *Hypisodus* sp. from the uppermost Brule of eastern Nebraska (Scott, 1940). Accordingly, Scott's measurements were used to ascertain if *Hypisodus* sp. Form B fit within the ranges determined in this study. Anterior-posterior dimensions reported here are within the range of Scott's measurements except for the first upper molar and the third molars. The length reported by Scott for the first upper molar is 3.0 mm, .1 mm less than the range found in this study and within two standard deviations of the mean. Scott's dimensions for both of the third molars exceeds the uppermost limits of the range but the small differences do not seem important inasmuch as great variability in third molars is not unusual and particularly so when the specimen was "an old animal with much worn teeth". *Hypisodus* sp. Form A and Form B should be referred to *Hypisodus minimus* Cope.

To determine if any significant changes had occured in the wear pattern of these teeth, scattergrams (Figs. 1-2) were made and correlation coefficients were determined for the influence of crown height on both occlusal crown width and occlusal crown length. The measurements show a significant negative correlation ($p < 0.05$) between the height of the crown and its occlusal width. This indicates that as the tooth wears, the transverse dimension increases. As for the relationship between crown height and occlusal crown length, a significant relationship ($p < 0.05$) is seen only in the upper first molar. The measurements in this case show a positive correlation indicating that as the tooth wears, its anterior-posterior dimension decreases.

The hypsodonty of these molars was examined for evidence of increased height during the Oligocene. No evidence for an increase in this dimension is shown on the basis of our material.

A final aspect of this study was to determine if variations in size occurred in successive sediments and to note any relationship between them (Figs. 3-4.). The figures show the relationship between the greatest crown width and greatest crown length at the base of the crown. These dimensions were used because the base of the crown is beneath the bone and not subject to wear. This eliminates the variation in size due to wear noted above (Figs. 1-2.). Among the lower molars the presence of specimens from the Lower, Middle, and Upper Oligocene are scattered randomly throughout the tight range of variation. Dimensions of some upper molars of the Lower and Upper Oligocene were found in the upper limits of a slightly more scattered range of variation. These data indicate that there was no basis for suggesting that variations in the dimensions of the molar teeth were related to their stratigraphic occurrence.

The best description of cusp patterns of the molar teeth of *Hypisodus* was given by Scott (1940). Galbreath (1953) noted variations in his specimens that deviated form Scott's descriptions. In this study all molars exhibited roots. Parastyles were noted on most molars but some, due to wear, showed faint evidence of their former presence. Ribs on the antero-buccal crescent were also seen on all molars but were more prominent on the upper molars. A variation noted in this study not discussed elsewhere was the presence of ectostylids, some incipient, on some lower first and second molars. These appeared in specimens of Lower and Middle Oligocene age. This variation, along with others reported by Scott or Galbreath, are not seen as significant.

The molars of *Hypisodus minimus* collected by Galbreath in northeastern Colorado do not vary measurably in size or in cusp pattern from the youngest deposits of the Lower Oligocene to the oldest desposits of the Upper Oligocene. In lieu of better evidence differences which exist are of no taxonomic value.

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Dentition	OCL	OCW	CH	GCL	GCW
Upper					
1st Molar:	N=11. Upper Chadronian (1), Orellan (9), Whitneyan (1).				
R (mm)	3.10-4.15	2.28-3.35	1.30-3.30	3.10-4.15	2.75-3.67
$\bar{X}$ (mm)	3.61	2.85	2.27	3.61	3.29
S.D.	0.35	0.37	0.78	0.35	0.30
2nd Molar:	N=12. Upper Chadronian (1), Orellan (10), Whitneyan (1).				
R (mm)	3.32-4.65	2.30-3.62	1.67-5.34	3.32-4.65	2.80-4.35
$\bar{X}$ (mm)	4.12	2.97	3.34	4.12	3.51
S.D.	0.42	0.48	1.19	0.42	0.40
3rd Molar:	N=17. Upper Chadronian (2), Orellan (14), Whitneyan (1).				
R (mm)	3.79-5.44	2.07-3.75	2.54-5.77	4.35-6.30	2.95-4.40
$\bar{X}$ (mm)	4.53	2.70	4.39	5.13	3.54
S.D.	0.45	0.54	1.24	0.51	0.45
Lower					
1st Molar:	N=29. Upper Chadronian (10), Orellan (19).				
R (mm)	2.10-3.88	1.40-2.36	1.00-3.80	2.73-3.88	1.60-2.45
$\bar{X}$ (mm)	3.25	1.90	2.33	3.27	2.08
S.D.	0.37	0.26	0.66	0.33	0.22
2nd Molar:	N=40. Upper Chadronian (11), Orellan (28), Whitneyan (1).				
R (mm)	3.20-4.21	1.55-2.62	2.12-5.77	3.20-4.21	1.79-2.90
$\bar{X}$ (mm)	3.72	2.01	3.85	3.73	2.30
S.D.	0.25	0.22	0.99	0.26	0.23
3rd Molar:	N=36. Upper Chadronian (11), Orellan (25).				
R (mm)	4.65-6.21	1.40-2.50	1.80-6.10	4.85-6.70	1.87-2.84
$\bar{X}$ (mm)	5.42	1.88	4.18	5.79	2.22
S.D.	0.39	0.25	1.17	0.41	0.25

Table 1. Ranges (R), means (X), and standard deviations (S.D.) for the occlusal crown length (OCL), occlusal crown width (OCW), crown height (CH), greatest crown length (GCL), and greatest crown width (GCW) of *Hypisodus Minimus*.

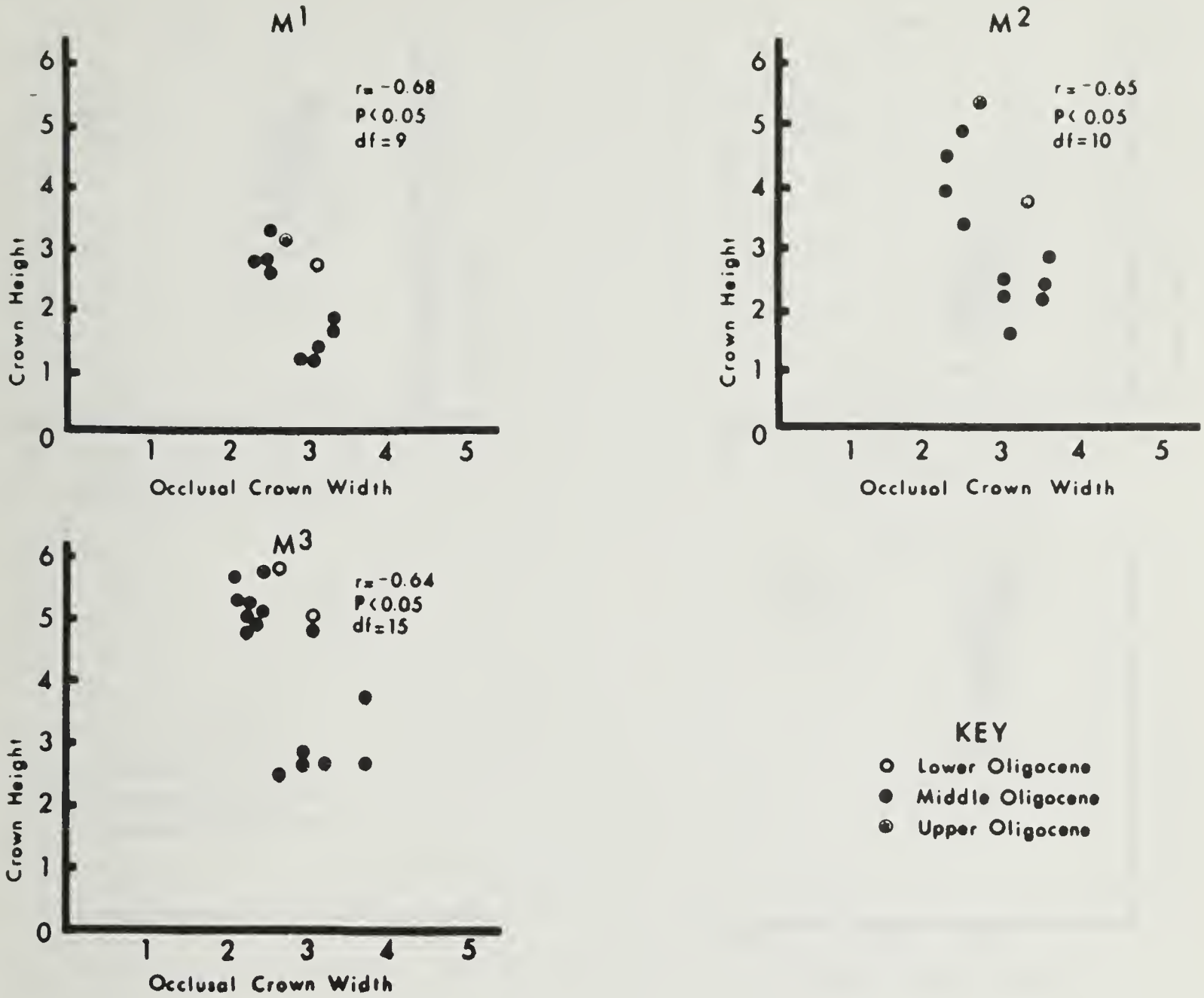

Figure 1. Scatergrams and correlation coefficients for the relationship between occlusal crown width (mm) and crown height (mm) of the upper molars of *Hypisodus minimus* from northeastern Colorado.

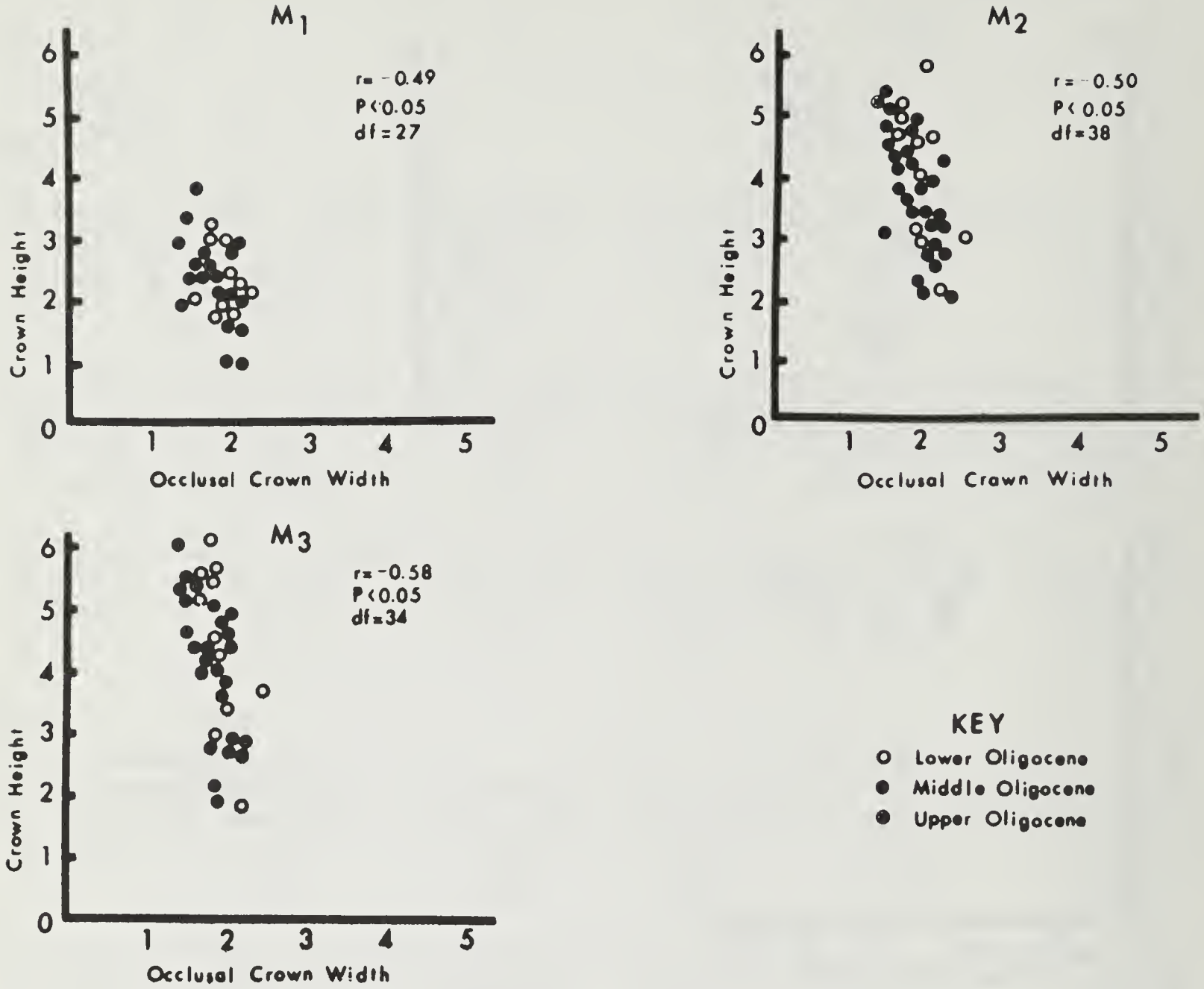

Figure 2. Scattergrams and correlation coefficients for the relationship between occlusal crown width (mm) and crown height (mm) of the lower molars of *Hypisodus minimus* from northeastern Colorado.

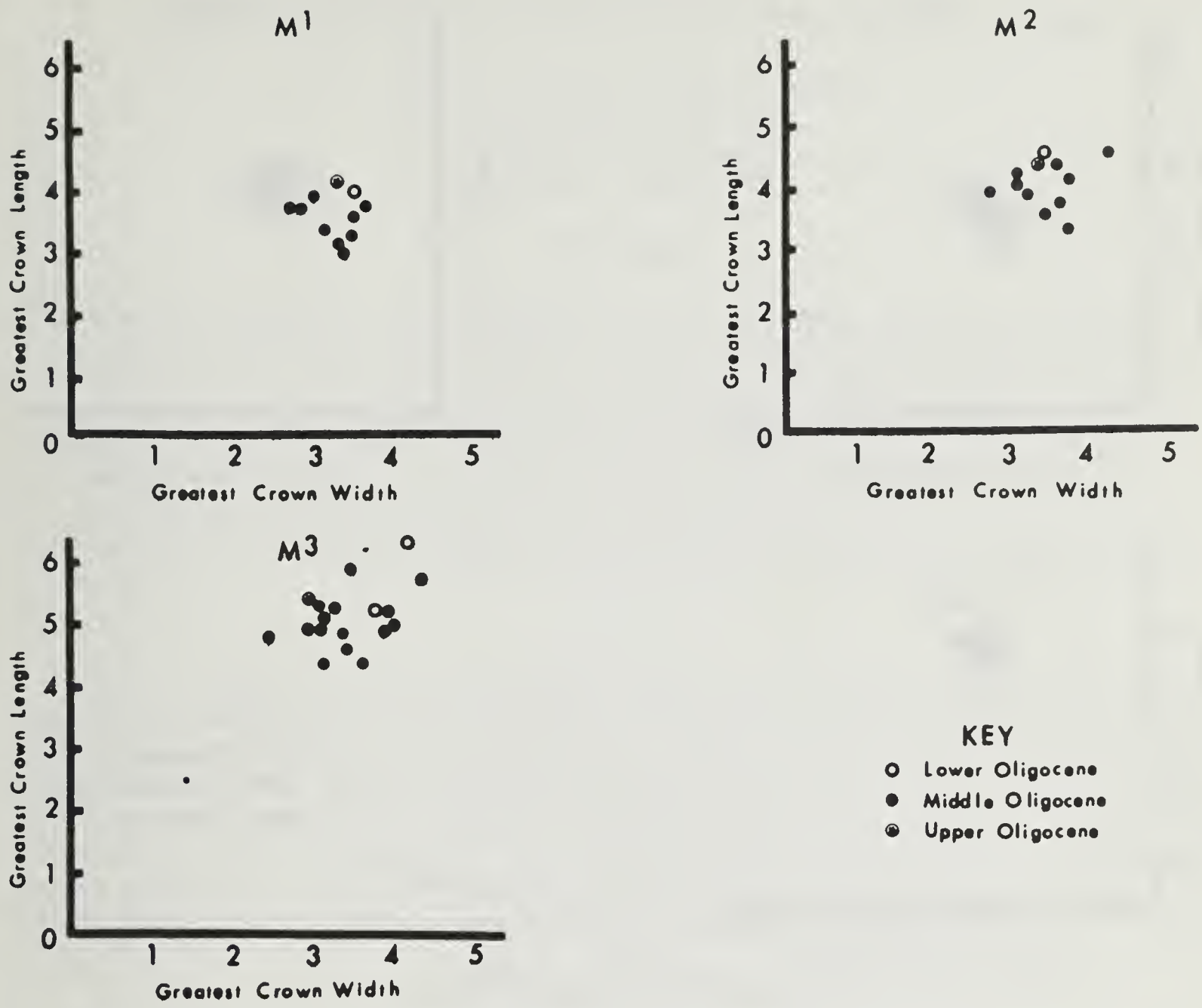

Figure 3. Scattergrams showing the range and relationships between greatest crown width (mm) and greatest crown length (mm) of the upper molars of *Hypisodus minimus* from northeastern Colorado.

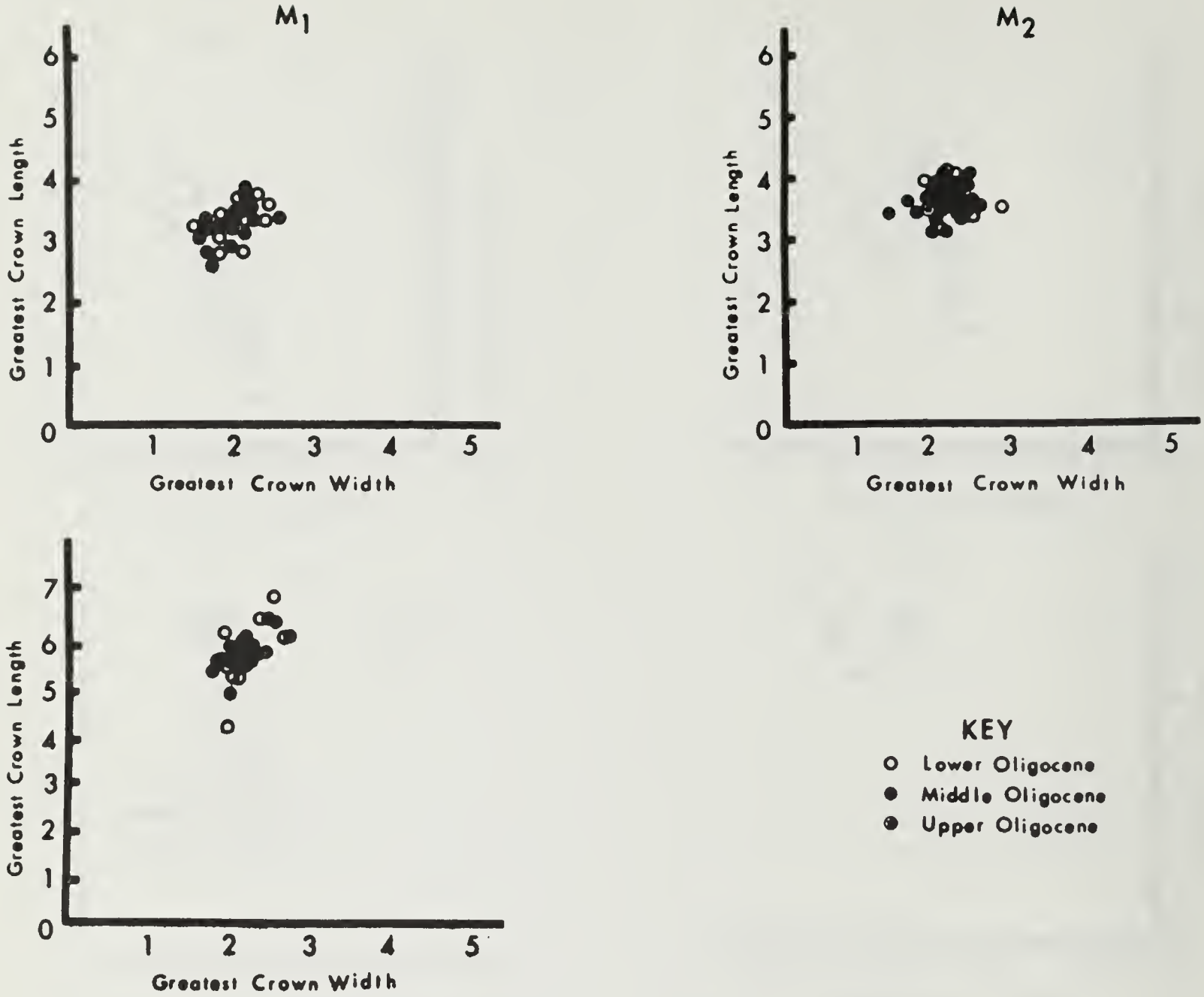

Figure 4. Scattergrams showing the range and relationships between greatest crown width (mm) and greatest crown length (mm) of the lower molars of *Hypisodus minimus* from northeastern Colorado.

FREQUENCY OF AQUATIC MACROPHYTES IN EAST-CENTRAL ILLINOIS

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ABSTRACT:

Aquatic plant communities of east-central Illinois were studied during the late summer of 1971 and 1976. Frequency, relative frequency, and frequency of dominance were calculated for the various taxa found. Some changes in species composition took place during the five year period, usually consiting of the addition or substraction of one species. Over-all, however, it was found that the aquatic communities have remained relatively static, as has the percent of ponds lacking aquatic plants. The taxa most commonly encountered were *Chara globularis* Thuill., *Jussiaes repens* L., *Lemna minor* L., *Najas guadalupensis* (Spreng.) Magnus, N. *minor* All., *Potamogeton foliosus* Raf., and *P. pusillus* L.

Aquatic vascular plants comprise a sizeable portion of the flora of Illinois. Some of these taxa choke waterways, hamper boating and fishing, and make recreational activities impossible. As a result, numerous studies concerning aquatic plants have been undertaken. In Illinois, the majority of these studies have been concerned with the distribution, by county, of the various taxa, yielding reasonable information on their geographic ranges. Studies such as these can, however, be misleading as to the actual frequency of the species. This paper is mainly concerned with presenting a more accurate picture of the aquatic vegetation in the east-central portion of Illinois, the distribution of many of the species, and the type of aquatic associations that exist.

MATERIALS AND METHODS

A total of 197 aquatic habitats in 14 counties were sampled in east-central Illinois. Of these aquatic habitats 95 are north of the Shelbyville moraine, the terminal moraine of 'Wisconsin glaciation, in the counties of Champaign, Coles, Douglas, Edgar, Ford, Moultrie, and Piatt, while the remaining 102 locations are south of the moraine in the counties of Clark, Crawford, Cumberland, Effingham, Jasper, Richland, and Shelby. Nearly all of the sampling was done in small, warm-water ponds. All sites were studied in the late summer of 1971 and again during the late summer of 1976. All species present in each aquatic habitat were recorded and their abundance determined. Notes were also taken at each location concerning the type of body of water, the depth at which the taxa were growing, and the size of the plant community. Voucher specimens are deposited in the Stover Herbarium of Eastern Illinois University (EIU); the nomenclature used follows Mohlenbrock (1975) and Stotler (1968).

The data obtained were considered to be analagous to quadrat data since each aquatic habitat was treated as though it was a single plot. From these data the frequency and the relative frequency were calculated for each species using the following formulas.

$$\text{Frequency (\%)} = \frac{\text{Total habitats of occurrence of a species}}{\text{Total habitats examined}} \times 100$$

$$\text{Relative Frequency} = \frac{\text{Total habitats of occurrence of a species}}{\text{Total habitats of occurrence of all species}} \times 100$$

Frequency of dominance was also calculated for each species that occured as a dominant member of a community. Frequency of dominance is defined as the total number of times of occurrence of a species as a dominant expressed as a percentage of its total number of times of occur-

rence. Dominance was determined through visual inspection of the pond. At times no dominance was recorded, while occasionally two species were found as dominants in the same pond.

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RESULTS AND DISCUSSION

Extensive literature is available concerning the distribution of the aquatic taxa of Illinois. A relatively comprehensive review was undertaken by Dolbeare and Ebinger (1974). The general ranges of most of the vascular aquatic macrophytes is also included in that study as well as in Mohlenbrock and Ladd (1978) and by Ebinger and Vogel (1977).

Though very useful, range maps can be extremely misleading in determining how common various aquatic taxa are in the state. For example, Dolbeare and Ebinger (1974) show that some taxa, such as *Ceratophyllum demersum* and *Potamogeton nodosus,* are well distributed, but the present study indicates that they are rarely encountered in more than one pond in any particular county. In contrast, other species, such as *Najas guadalupensis* and *P. foliosus* occur frequently, being found in many of the aquatic habitats visited (Table 1).

A total of 31 aquatic macrophytes are included in the present study. These species are listed in Table 1 along with the number of counties in which they were found, their frequency, and relative frequency north and south of the Shelbyville moraine. Taxa having relative frequencies greater than 7 are considered to be common. These include *Chara foliolosa, C. globularis, Jussiaea repens, Lemna minor, Najas guadalupensis, N. minor, Potamogeton diversifolius, P. foliosus,* and *P. pusillus.* At least in east-central Illinois some of the species exhibit definite north-south distribution tendencies. *Bacopa rotundifolia, Chara braunii, Jussiaea repens, Najas gracillima, N. minor,* and *Potamogeton diversifolius* occur most commonly south of the moraine, while *Chara contraria, C. globularis, C. inconnexa, Myriophyllum exalbescens, Potamogeton pectinatus* and *Ranunculus longirostris* are more commonly encountered north of the moraine. Dolbeare and Ebinger (1974) and Ebinger and Vogel (1977 found that many of these species exhiit a similar statewide distribution pattern.

Many of the ponds studied exhibited some change in floristic composition between 1971 and 1976, usually consisting of the addition or subtraction of one species. Also, the frequency and relative frequency figures for 1976 (Table 1), for the most part, tend to be slightly lower than those obtained from 1971. The most probable reason for this is that a severe drought occurred during the summer of 1976, drastically lowering water levels in many of the ponds. The changes observed are relatively minor, however, as it was found that the frequency of the taxa has remained relatively static,

A large complement of the ponds surveyed contained no aquatic macrophytes. In 1971, 24% were sterile while in 1976, 29% lacked aquatic macrophytes. It is suspected that these figures will remain relatively static, with the discrepancy again probably due to the drastic summer drawdown caused by the drought. Commonly very riled waters due to wading livestock were sterile, as were ponds with very steep slopes. It is also a common practice of many pond owners to periodically poison the ponds. In many cases this fact was substantiated through personal communication. Also, some ponds surveyed were in conjunction with feed lots, subjecting them to vast amounts of raw sewage run-off. The extensive algal blooms in these ponds prevented higher plant growth with the occasional exception of the Lemnaceae.

In Table 2 the frequency of dominance is included to indicate the competitive ability of the taxa studied. It must be cautioned that this figure shoud be treated in conjunction with the total number of locatities in which the species was found as well as the total number of times the species was the dominant taxa. A species which was encountered twice and occurred as a dominant once will not have an accurate frequency of dominance due to a lack of a representative sample.

Table 1. Aquatic macrophytes observed with their frequencies, relative frequencies, and number of counties in which they were found north and south of the terminal moraine in east-central Illinois.

SPECIES	North (1976)			North (1971)			South (1976)			South (1971)		
	Cos. #	Freq. %	Rel. Freq.	Cos. #	Freq. %	Rel. Freq.	Cos. #	Freq. %	Rel. Freq.	Cos. #	Freq. %	Rel. Freq.
FREE-FLOATING SPECIES												
Lemna minor L.	6	17	10	5	21	12	5	11	7	4	16	8
L. obscura (Austin) Daubs	-	-	-	-	-	-	2	3	2	-	-	-
Spirodela polyrhiza (L.) Schleiden.	2	3	2	3	5	3	2	3	2	3	4	2
Wolffia columbiana Karst.	2	2	1	3	3	2	2	2	1	1	1	1
W. papulifera Thompson.	3	4	3	2	2	1	1	2	1	1	2	1
SUBMERSED SPECIES												
Ceratophyllum demersum L.	3	5	3	4	5	3	1	2	1	3	3	2
Chara braunii Gmel.	-	-	-	-	-	-	1	2	1	1	2	1
C. contraria A. Br. ex Kutz.	2	5	3	2	4	2	-	-	-	-	-	-
C. foliolosa Muhl.	3	5	3	2	3	2	6	17	10	6	14	7
C. globularis Thuill.	5	14	8	4	10	5	1	2	1	2	2	1
C. inconnexa T. F. Allen.	1	2	1	3	3	2	-	-	-	-	-	-
C. zeylanica Klein ex Willd.	1	1	1	-	-	-	1	1	1	1	1	1
Elodea nuttallii (Planch.) St. John.	1	1	1	1	1	1	1	1	1	1	2	1
Myriophyllum exalbescens Fern.	3	5	3	2	4	2	-	-	-	1	1	1
Najas flexilis (Willd.) R. & S.	1	3	2	1	1	1	-	-	-	1	1	1
N. guadalupensis (Spreng.) Magnus.	5	10	6	6	13	7	6	14	8	5	15	8
N. gracillima (A. Br.) Magnus.	-	-	-	-	-	-	2	2	1	2	4	2
N. minor All.	1	3	2	2	4	2	6	20	12	6	14	7
Potamogeton crispus L.	2	7	4	2	6	4	-	-	-	-	-	-
P. diversifolius Raf.	-	-	-	-	-	-	6	16	9	6	22	12
P. foliosus Raf.	7	36	21	7	50	27	7	16	9	7	37	20
P. nodosus Poir.	3	4	3	3	6	4	3	3	2	4	7	4
P. pectinatus L.	7	11	6	6	10	5	2	2	1	2	4	2
P. pusillus L.	6	17	10	5	10	5	6	15	9	3	6	3
Ranunculus longirostris Godr.	2	2	1	4	5	3	-	-	-	-	-	-
EMERGENT SPECIES												
Bacopa rotundifolia (Michx.) Wettst.	-	-	-	-	-	-	3	3	2	4	6	3
Jussiaea repens L.	2	4	3	2	4	2	6	16	9	6	14	7
Ludwigia palustris (L.) Ell.	1	1	1	1	1	1	4	10	6	3	4	2
Nelumbo lutea (Willd.) Pers.	1	1	1	1	1	1	1	1	1	-	-	-
Nuphar lutea L.	2	2	1	2	3	2	2	2	1	2	2	1
Nymphaea tuberosa Paine.	1	1	1	1	1	1	1	1	1	1	1	1

Table 2. Frequency of dominance and sociability of submersed aquatic macrophytes north and south of the terminal moraine in east-central Illinois during late summer 1976.

SPECIES	NORTH OF THE MORAINE							SOUTH OF THE MORAINE						
	Total locations	Total dominant	Frequency of dominance	Only species	Associated with one species	Associated with two species	Associated with 3 or more species	Total locations	Total dominant	Frequency of dominance	Only species	Associated with one species	Associated with two species	Associated with 3 or more species
Ceratophyllum demersum	5	4	80	1	1	2	1	2	2	100	2	-	-	-
Chara braunii	-	-	--	-	-	-	-	2	-	--	-	1	1	-
Chara contraria	5	2	40	-	1	-	4	-	-	--	-	-	-	-
Chara foliolosa	5	3	60	1	1	-	3	17	11	65	9	7	-	1
Chara globularis	13	5	38	3	3	3	4	2	-	--	-	-	-	2
Chara inconnexa	2	-	--	-	1	-	1	-	-	--	-	-	-	-
Chara zeylanica	1	1	100	-	-	-	1	1	-	--	-	-	1	-
Elodea nuttallii	1	-	--	-	-	1	-	1	1	100	-	-	-	1
Myriophyllum exalbescens	5	4	80	1	-	-	4	-	-	--	-	-	-	-
Najas flexilis	3	1	33	-	-	1	2	-	-	--	-	-	-	-
Najas guadalupensis	9	5	56	2	1	1	5	14	11	79	2	5	1	6
Najas gracillima	-	-	--	-	-	-	-	2	1	50	-	1	1	-
Najas minor	3	2	66	-	1	2	-	20	13	65	6	6	2	6
Potamogeton crispus	7	4	57	3	-	1	3	-	-	--	-	-	-	-
Potamogeton diversifolius	-	-	--	-	-	-	-	16	9	56	7	6	-	3
Potamogeton foliosus	32	18	56	13	7	6	6	16	11	69	7	6	2	1
Potamogeton nodosus	6	3	50	3	-	-	3	3	1	33	-	-	1	2
Potamogeton pectinatus	10	2	20	-	4	2	4	2	1	50	1	-	-	1
Potamogeton pusillus	16	8	50	1	6	2	7	15	7	47	5	6	-	4
Ranunculus longirostris	2	2	100	-	1	-	1	-	-	--	-	-	-	-

Of the taxa that were commonly encountered many had a high competative ability, and were the dominant species in more than half of the habitats in which they were found. Included in this group are *Chara foliolosa, Najas guadalupensis, N. minor, Potamogeton diversifolius, P. foliosus,* and *P. pusillus.* Also, *Ceratophyllum demersum* and *Myriophyllum exalbescens,* when found, were usually the dominant member of the aquatic community. These two taxa were rather infrequent in occurrence, but when conditions were conducive for their growth, they exhibited a high competitive ability (Table 2). *Ceratophyllum demersum* was found seven times and was the dominant taxon in six of the habitats, while *Myriophyllum exalbescens* dominated four of the five communities in which it was found. *Najas minor* is also a species worthy of mention. This Eurasian taxon, which is now well represented in the southern half of the state, was first reported for Illinois by Fore and Mohlenbrock (1966). It tends to be very competitive, occurring frequently as a dominant, forming very dense mats of submersed vegetation. The rapid spread of this taxon indicates that it is becoming a serious problem in the state.

The sociability of the submersed aquatic taxa was determined by the number of times each taxon was the only species present, or associated with one, two, or three or more taxa (Table 2). Most of the species that were commonly encountered appear to have a high degree of sociaility, usually occurring with one or more species. Of the taxa found north of the moraine, *Ceratophyllum demersum, Chara globularis, Myriophyllum exalbescens, Najas guadalupensis, Potamogeton foliosus, P. pectinatus* and *P. pusillus,* were commonly associated with other taxa, as were *N. guadalupensis, N. minor, P. foliosus, and P. pusillus* south of the moraine. In contrast, *Chara foliolosa* and *Potamogeton diversifolius* were the only species present in about half of the localities in which they were found, while *Potamogeton foliosus* was the only species present in about one third of the habitats in which it was found (Table 2). These three taxa appear to be early successional species, and were commonly the only species present in the younger ponds studied.

Though most of the species have a fairly high sociability, few distinct, consitent associations were found. In general, the likelihood of anyone taxon being associated with a particular species was fairly low, and the compostion of the plant communities observed was random. A few consitent association were found however. North of the maraine *Potamogeton foliosus* was commonly associated with *Ceratophyllum demersum* (4 of the 5 locations), while *Chara globularis* was commonly associated with *P. foliosus* (6 of the 13 locations) or *P. pusillus* (6 of the 13 locations). South of the moraine *Najas minor* was commonly associated with *N. quadalupensis* (8 of the 14 locations).

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LUTEINIZING HORMONE AND SOCIAL STRESS IN *MICROTUS OCHROGASTER*

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ABSTRACT. Experiments were conducted to determine if variation in plasma LH could be used as an indicator of social stress in cycling populations of *Microtus ochrogaster.* Circulating LH and release of LH after injection of LH-RH were similar in crowded and the uncrowed groups. LH does not appear to be a suitable indicator of social stress in *M. ochrogaster.*

INTRODUCTION

Among the various hypothesis that have been proposed to explain periodic (''cyclic'') fluctuations in abundance of certain small microtine rodents, social stress has perhaps attracted the most attention over the years (Christian, 1955; Louch, 1956; Christian and Davis, 1964; Bailey, 1966; Andrews, 1970). The social stress hypothesis involves hypothalamic-hypophyseal-adrenocortical responses to increased social interference resulting from increases in population density. In an attempt to mobilize resources of the individual to meet increased energy demands imposed by social stress, it has been proposed that the hypothalamic-hypophyseal system increases production of adrenocortical stimulating hormone (ACTH). There is also proposed to be a concurrent decrease in production of growth hormone (somatotrophin) and the gonadotrophins, luteinizing hormone (LH) and follicle stimulating hormone (FSH). ACTH stimulates release of adrenocortical hormones, including glucocorticoids, which mobilize energy reserves of the animal (i.e., conversion of liver glycogen to circulating glucose and conversion of protein to glucose). This permits the animal to provide energy necessary for establisment of a physiological homestasis. However, side effects from the glucocorticoids are proposed to result in higher mortality and decreased reproduction, thus triggering a population decrease (Christian and Davis, 1964).

Most analysis of this hypothesis have relied upon indirect measures of socio-physiological stress, i.e., weights of the adrenal, spleen and thymus, number of circulating white blood cells and pathologic changes in kidneys and adrenals (Christian, 1971; Christian and Davis, 1964). Andrews (1968, 1970) and Andrews and Strohben (1971) attempted more direct measures of adrenal function through organ culture of adrenals. This latter method introduces the possibility of experimental artifacts unrelated to social stress, however. The above described endocrine system (especially glucocorticoid production and associated organ changes) also responds to a variety of non-population stresses (i.e., weather and food quality, as well as handling stress). Results of previous studies have therefore proved inconclusive, primarily because of the inability to isolate endocrine changes resulting from other non-density induced stresses.

Owing to the inability to measure accurately both qualitative and quantitative changes in adrenocortical responses to social stress alone, glucocorticords do not provide a satisfactory assay for the study of the social stress hypothsis. Methodology is not yet available for measurement of circulating ACTH in wild rodents without sacrificing the animals, and thus seriously disrupting the population. Even if ACTH could be assayed, non-social stresses such as capturing and handling the animals, would bias the resulting data. Pituitary gonadotrophins (LH and FSH) appear to be less responsive to non-density stresses than are ACTH and glucocorticoids; if so handling and anesthesia bias would be reduced. Both LH and FSH can be assayed from small quantities (◄1.0 cc) of blood (Hauffe, 1977); thus, individuals can be sampled without significant mortality to the

population. The pituitary releases larger quantities of LH than FSH in response to given doses of gonadotrophin releasing hormone (LH-RH) (Schally *et al.*, 1973); hence,ability of the pituitary to release LH can be measured more easly than can be release of FSH.

If the social stress hypothesis is valid, one should observe lower levels of circulating LH and/or a lesser ability of the pituitary to release LH in stressed than in unstressed animals. A study was therefore made to determine if LH could be employed to investigate the social stress hypothesis in the prairie vole (*Microtus ochrogaster*), a ''cyclic'' species.

METHODS

A 1.0 cc sample of blood was removed from the external jugular vein of each animal under light ether anesthesia with a 5 cc heparinized syringe. This amount was usually sufficient for an accurate measurement of LH, but not fatal to the animal. After the blood sample was taken, the wound was sutured. Blood samples were collected in heparinized 12x75 mm plastic culture tubes and centrifuged at 1600 g for 20 min. The plasma was removed, frozen and later assayed for LH.

Responses to LH-RH were studied by a subcutaneous injection of synthetic LH-RH (Abbott Laboratory) (diluted in phosphosaline buffer-1/gelatin at a concentration of 1 ng/m1) administered to each animal after an initial blood sample was taken. Doses of 30 ng for females and 40 ng for males were determined to elicit a response in plasma LH which was between values of uninjected animals and animals responding maximally to high doses of LH-RH. Twenty minutes after injection a second blood sample was taken from each animal.

Blood LH levels were measured with a double antibody LH RIA kit supplied by the Rat Pituitary Hormone Distribution program, NIAMD (Hauffe, *et al.*, In Prep.). Purified rat LH (NIAMD-Rat LH I-4) was iodinated with Na 125I (New England Nuclear). Rat LH (NIAMD-Rat LH-RP-1) was employed as the reference standard and NIAMD-Anti-Rat LH serum S-3 was used as the antibody. Bound hormone was precipitated with anti-rabbit-gamma globulin.

All animals used in this study were taken from a colony that had been maintained in the laboratory for at least 10 generations. Virgin animals approximately 40 days old were used in all experiments.

Base levels of circulating LH were obtained from 11 adult males and 5 adult non-pregnant females that had been isolated in 20 x 36 x 15 cm breeding cages (provided with wood shavings, No. 345211 purina rabbit chow and water) for one week. An additional four animals (1 male, 3 females), similarly maintained, were used to test the effect of acute handling stress on LH levels in blood samples taken 20 min apart. These animals were bled, injected with 40 m1 of phosphaline buffer-1% gelatin and then bled again after 20 min.

The following experiments were conducted to determine the possible relationship between social stress and levels of circculating LH:

Experiment I. Group of eight similar weight animals (4 males, 4 females) were placed in 20 x 36 x 15 cm cages, as described above, at 21 days of age. Uncrowded control animals were caged in pairs (1 male, 1 female). Animals were kept under these conditions fo four weeks.

At the termination of each trial all animals were weighed, bled, and tested for LH-RH responsiveness. Autopsies were performed on all animals to determine pregnancy of females; various organs (ovaries, uteri, testes, seminal vesicles, ardenals and spleens) were weighed on a Roller-Smith Precision balance.

Uncrowded animals generally appeared to be in good health at the end of each trial period. All crowded animals were severely stressed as indicated by numerous large scars on their bodies and by enlarged spleens. Percent mortality also indicated a higher degree of stress was imposed upon the crowded than on the uncrowded animals (crowded: 28.4%, n = 67; uncrowded: 0%, n = 44). Pregnancies were observed in 16.7% of the crowded females. Paturition did not occur in any of the crowded females while all pregnant uncrowded females bore litters.

Experiment II. Animals were maintained from 1 August to 1 December 1976 in 3 x 3 m outdoor pens in which grew various speccies of grasses and forbs. Three pens each contained 10-14

animals (1:1 sex ratio); each pen had one large feeding station, one continuosly dripping water station and one large nest box. Five similar pens were used as controls; each contained only 4 animals (2 males, 2 females) and were provided with 4 continuously dripping water stations, 3 feeding stations and 8 small nest boxes. Plywood boards (approximately 250 x 20 x 2 cm) were also placed inside these pens to subdivide the surface into 5-6 separate areas.

All animals were individually marked by toe-clipping. Each enclosure was live-trapped once every 2 weeks and selected animals bled. The animals were isolated in cages with food and water for 48 hours after bleeding and then released back into the enclosures in which they were caught.

RESULTS AND DISCUSSION

Plasma LH values in the isolated voles were: males, 226 ± 27.9 ng/m1 (mean ± 1 S.E.); females, 370 ± 106.6 ng/m1. These have been used as base values for comparative purposes. There was no significant change in plasma levels in animals 20 min after injection of a buffer solution, thus indicating that stress owing to handling and bleeding did not alter LH levels. Changes in LH values after exogenous LH-RH injections should therefore reflect only responsiveness of the pituitary to LH-RH.

Experiment I. There was no significant difference in initial circulating LH levels in the two groups of males (Table 1). All but 3 of

TABLE 1. Results of experiment I: average base levels and standard errors of circulating LH in crowded prairie voles and the amount of increase following injection of LHRH. See methods for experimental conditions. Numbers in parentheses are sample sizes.

	LH (ng/m1 plasma)	
	Crowded	Uncrowded
Base level circulating LH		
Males	134.2 ± 23.2(13)	115.9 ± 10.3(15)
Females	156.9 ± 27.3(9)	206.4 ± 19.8(3)
Amount of *increase* in circulating LH following injection of LHRH		
Males	115.1 ± 19.4(12)	79.9 ± 12.1(14)
Females	121.5 ± 72.4(7)	————

the uncrowded females were pregnant; sufficient data for statistical analysis were therfore not available for this group. Increase in plasma LH levels after injection of LH-RH were not significantly different between 12 crowded and 14 uncrowded males: Crowded males tended to display greater response to LH-RH than did uncrowded males.

The spleen was the only organ which showed significant difference in weight (expressed as percent body weight; body weights did not differ) between the two groups of males (crowded, 0.307 ± 0.08%; uncrowded, 0.089 ± 0.001%).

Experiment II. there was no significant difference between plasma LH levels of the crowded and uncrowded males and females in the outdoor enclosures, 161.1 ± 3.72 and 166.1 ± 37.6 ng/m1 for 6 crowded and 13 uncrowded males, respectively, and 214.7 ± 68.9 and 239.5 ± 52.0 ng/m1 for 6 crowded and 15 uncrowded females, respectively.

The results of these experiments do not indicate a negative correlation between potential

social stress and levels of circulating LH. In Experiment I the animals displayed the classical manifestations of severe social stress, i.e., fighting, injury, mortality, enlarged spleens, and reduced reproduction. LH levels were actually highest (although not significantly so) in the crowded animals, however. Likewise, there was a significantly greater response to exogenous LH-RH in the crowded males, indicating greater potential for LH release in stressed than in unstressed animals. Both these observations are the reverse of those expected for support of the social stress hypothesis. In the outdoor pens there was no difference in amount of circulating LH in either crowded or uncrowded animals of either sex. In all experimental situations, however, the levels of circulating LH were approximately 100 ng/m1 (27-44%) lower than the basal levels from isolated, and supposedly less stressed, individuals.

From these observations it appears to us that neither circulating LH nor the responsiveness of the pituitary to LH-RH agrees with proposed endocrine phenomena associated with the social stress hypothesis. As such, the LH system does not provide a suitable index of social stress for studies of this hypothesis. Our observations do not refute the social stress hypothesis; they do indicate, however, LH is not involved in the proposed manner. It is possible that variation in the ACTH-glucocorticoid system is the primary mechanism whereby social interference produces a negative feedback, resulting in population cycles in microtine rodents. Methodology to investigate these endocrine functions does not yet appear satisfactory to examin the social stress hypothesis in freeliving populations, however.

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RANKING AND UNRANKING UNORDERED BINARY TREES

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ABSTRACT

Given a finite set X with N elements ordered by a linear order $<$, an order isomorphism $\phi : X \to \{0, 1, \ldots, N-1\}$ is the ranking function; ϕ^{-1} is the unranking function. Ranking and unranking functions are constructed for the set of unordered binary trees with n leaves, $n \geq 1$. The unranking function is applied to random generation of unordered binary trees and isomorph rejection of ordered binary trees.

INTRODUCTION

The problem of ranking ordered binary trees has been considered in [3], [5], [7], [8], [9], [10], and [11]. In this paper the problem of ranking and unranking unordered binary trees will be considered. The general mothod is similar to that in §2 and §3 of [7]. One result is an efficient isomorph rejection algorothm for ordered binary trees.

If X is a finite set with $|X|=N$ and $<$ is a linear order on X, the ranking function on X with respect to $<$ is an order isomorphism

$$\phi : X \to \{0, 1, \ldots, N-1\}$$

with the usual ordering on the integers. The inverse map, ϕ^{-1}, is the unranking function.

An unordered binary tree is defined as follows:

(i) A single vertex v is an unordered binary tree with root v;

(ii) if T_1 and T_2 are unordered binary trees with roots r_1 and r_2 respectively, the object obtained by joining r_1 and r_2 to a new root r is a binary tree.

In particular, the left-right ordering of T_1 and T_2 is immaterial (see Figure 1).

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In (ii) above, r is the parent of r_1 and r_2; r_1 and r_2 are the children of r; and T_1 and T_2 are the subtrees of T rooted at r_1 and r_2, respectively. For a vertex other than r, r_1, r_2, the notions of parent, child, and subtree may be defined similarly.

For any unordered binary tree, the root is the only vertex with no parent, and every vertex has either two children or no children. A vertex with no children is a leaf; a vertex which is not a leaf is internal. In particular, the unordered binary tree consisting of one vertex has one leaf and no internal vertices.

Lemma 1: Every unordered binary tree has an odd number of vertices; an unordered binary tree with 2n-1 vertices has n leaves.

Proof: Easy induction.

Q.E.D.

Denote by b_n the number of unordered binary trees with n leaves.

Lemma 2: The numbers b_n satisfy the recurrence:

$$(1)\quad b_n = \begin{cases} 1 & n=1; \\ \displaystyle\sum_{\nu=1}^{\frac{n-1}{2}} b_\nu \, b_{n-\nu} & n>1, \text{ odd}; \\ \displaystyle\sum_{\nu=1}^{n/2-1} b_\nu \, b_{n-\nu} + \tfrac{1}{2}\left(b_{n/2}^2 + b_{n/2}\right) & n>1, \text{ even}. \end{cases}$$

Proof: In the recursive definition of unordered binary tree, let T_1 have n_1 leaves and T_2, n_2 leaves. Then $n=n_1 + n_2$, and without loss of generality, $n_1 \leq n_2$.

If n is odd, $n_1 \leq (n-1)/2$ and $(n+1)/2 \leq n_2$. For each ν, $1 \leq \nu \leq (n-1)/2$ there are b_ν ways of choosing T_1, and for each choice of T_1 there are $b_{n-\nu}$ choices for T_2. The second line in (1) follows.

If n is even, for each ν, $1 \leq \nu \leq n/2 - 1$, an argument similar to that above yields the summation in the third line of (1). If $n_1 = n_2 = n/2$, there are $\binom{b_{n/2}}{2}$ ways of choosing T_1 and T_2 distinct, and $b_{n/2}$ ways

of choosing $T_1 = T_2$. The last term in the third line of (1) follows.

THE RANKING FUNCTION

Let B_n be the set of unordered binary trees with n leaves. A total order $<$ may be defined on B_n recursively: assume that for $1 \leq k \leq n-1$, B_k is totally ordered by $<$, and also define $T < T'$ if T' has more leaves that T. Let $T_1, T_2 \in B_n$ with roots r_1 and r_2 respectively; further suppose that the subtrees rooted at the children of r_1 and r_2 are T_{11}, T_{12}, T_{21}, and T_{22} respectively. Without loss of generality, $T_{11} \leq T_{12}$, $T_{21} \leq T_{22}$ (see Figure 2). Then $T_1 < T_2$ if and only if

(i) $T_{11} < T_{21}$; or

(ii) $T_{11} = T_{21}$ and $T_{12} < T_{22}$.

Since $b_1 = 1$, it is easy to see that this definition gives a linear order on B_n.

Let $T \in B_n$ with root r; let $T_1 \in B_{n_1}$, $T_2 \in B_{n_2}$ will be the subtrees rooted at the children of r (if n=1, T_1 and T_2 don't exist, of course). Assume that $T_1 \leq T_2$; define

$$\phi_n(T) = \begin{cases} 0 & n=1; \\ \sum_{\nu=1}^{n_1-1} b_\nu \, b_{n-\nu} + \phi_{n_1}(T_1) b_{n_2} + \phi_{n_2}(T_2) & n_1 < n_2: \\ \sum_{\nu=1}^{n/2-1} b_\nu \, b_{n-\nu} + \phi_{n/2}(T_1) \, b_{n/2} - \tfrac{1}{2} \phi_{n/2}(T_1) \, (\phi_{n/2}(T_1) + 1) & \\ \quad + \phi_{n/2}(T_2) & n_1 = n_2 = n/2. \end{cases} \tag{2}$$

Theorem 1: The function ϕ_n is the ranking function of B_n with respect to $<$.

Proof: By the definition of ranking function, it suffices to show that

$$\phi_n(T) = \left| \{ S \in B_n : S < T \} \right|.$$

The proof is by induction on n. The case n=1 is immediate since $b_1 = 1$.

Suppose that $n > 1$ and the theorem is true for 1, 2, ..., n-1. Let $S \in B_n$, $S < T$. Let S_1, S_2 be the subtrees rooted at the children of the root of S; without loss of generality, $S_1 \leq S_2$.

Let $n_1 < n_2$; there are three possibilities for $S < T$: S_1 has fewer leaves than T_1; $S_1 \in B_{n_1}$ and $S_1 < T_1$; or $S_1 = T_1$ and $S_2 < T_2$. The first possibility occurs

$$\sum_{\nu=1}^{n_1-1} b_\nu \, b_{n-\nu}$$

ways; the second possibility occurs $\phi_{n_1}(T_1)b_{n_2}$ ways; and the third, $\phi_{n_2}(T_2)$ ways. The case $n_1 < n_2$ follows.

Let $n_1 = n_2$; the summation in this case arises as in the previous case. Suppose that $S_1 \in B_{n/2}$, $S_1 < T_1$. Then $\phi_{n/2}(S_1) = i$ where $0 \leq i \leq \phi_{n/2}(T_1)-1$. For each choice of S_1 there are $b_{n/2} - i$ choices of S_2 such that $S_1 < S_2$.

So there are

$$\sum_{i=0}^{\phi_{n/2}(T_1) - 1} (b_{n/2} - i) = \phi_{n/2}(T_1)b_{n/2} - \tfrac{1}{2} \phi_{n/2}(T_1)(\phi_{n/2}(T_1)-1)$$

trees $S \in B_n$ with $S_1 \in B_{n/2}$, $S_1 < T_1$.

If $S_1 = T_1$, there are $\phi_{n/2}(T_2) - \phi_{n/2}(T_1)$ choices for S_2 satisfying $S_1 \leq S_2 < T_2$. The formula for the case $n_1 = n_2 = n/2$ follows.

Q.E.D.

At this point a question arises: how difficult is it to compute $\phi_n(T)$? More precisely, in terms of fundamental operations (addition, substraction, multiplication, division, and comparison of numbers), can the number of operations required to compute $\phi_n(T)$ be estimated? Notationally, if functions $f(n)$, $g(n)$ satisfy the relation

$$af(n) \leq g(n) \leq bf(n), \quad n \geq 0$$

for constants, a, b, write $g(n) = 0\ (f(n))$. Then the question posed above can be answered.

Theorem 2: Computation of $\phi_n(T)$ is at most $0(n^2)$. Exclusive of calculating $b_1, \ldots, b_{n-1}$, the computation of $\phi_n(T)$ is, in the worst case, $0\ (n \log n)$, where the logarithm is to base 2.

Proof: It is clear that calculation of $b_1, \ldots, b_{n-1}$ by means of (1) requires $0(n^2)$ operations, and no simple closed formula is known for b_n[2].

Given that $b_1, \ldots, b_{n-1}$, are known, let $t(n)$ denote the number of operations required to compute $\phi_n(T)$ in the worst case. Then $t(n)$ satisfies

$$t(n) = \max_{1 \leq n_1 \leq n/2} \{t(n_1) + t\ (n_2) + 0(n_1)\}$$

where n_1, n_2 have their usual interpretation. Then there are constants, α, β such that

$$t(n) \leq \begin{cases} \alpha & n_1 = 1; \\ \max\limits_{1 \leq n_1 \leq n/2} \{t(n_1) + t(n_2) + \beta n_1\} & n_1 > 1. \end{cases}$$

It is easy to show from this that

$$t(n) \leq \alpha n + g_1(n)\beta$$

where

$$g_1(n) \begin{cases} =0 & n = 1; \\ \leq \beta & n=2; \\ \leq \max \{ g_1(n_1) + g_1(n_2) + \beta n_1 \} & n > 2. \\ 1 \leq n_1 \leq n/2 & \end{cases}$$

As above, it is easy to show that

$$g_1(n) \leq (n-1)\ \beta + g_2(n)$$

Where

$$g_2(n) \begin{cases} =0 & 1 \leq n \leq 3; \\ \leq \beta & n = 4 \\ \leq \max \{ g_2(n_1) + g_2(n_1) + \beta\ n_1 \} & n > 4. \\ 1 \leq n_1 \leq n/2 & \end{cases}$$

In general, suppose that

$$g_i(n) \begin{cases} =0 & 1 < n < 2^i - 1; \\ \leq \beta & n = 2^i; \\ \leq \max \{ g_i(n_1) + g_i(n_1) + \beta\ n_1 \} & n > 2^i. \\ 1 \leq n_1 \leq n/2 & \end{cases}$$

Then for $2^i \leq n \leq 2^{i+1}-1$, $g_i(n) \leq (n-2i-1)\beta$ since $g_1(n_1) = 0$ for $0 \leq n, \leq 2^i-1$; and $g_i(2^{i+1}) \leq 2^i\ \beta + 2\beta$. So $g_i(n)$ may be bounded:

$$g_1(n) \leq (n-2^i+1)\beta + g_{i+1}(n)$$

where

$$g_{i+1}(n) \begin{cases} =0 & 1 \leq n \leq 2^{i+1}-1; \\ \leq \beta & n = 2^{i+1}; \\ \leq \max \{ g_{i+1}(n_1) + g_{i+1}(n_2) + \beta n, \} & n > 2^{i+1}. \\ 1 \leq n_1 \leq n/2 & \end{cases}$$

Let i_o = [log n + 1] (where [ ] denotes the greatest integer function); then

$$t(n) \leq n + (n-1)\beta + (n-3)\beta + \ldots + (n-2^{i_o}+1)\beta + g_{i_o}(n).$$

But $g_{i_o}(n) = 0$; hence $t(n) \leq n + (n \log n)\beta$

On the other hand, $t(n) \geq 2t(n/2) + \gamma n$ for some constant γ , from which it follows that $t(n) \geq \delta\, n \log n$ for some constant δ [1].

Q.E.D.

THE UNRANKING FUNCTION

The problem to be solved is: given integers r, n satisfying $n \geq 1$, $0 \leq r \leq b_n - 1$, construct the rank r unordered binary tree in B_n.

The unranking algorithm is also computed using equation (2). Let T be the rank r tree in B_n; let T_1, T_2, n_2 be as before. The idea is to use equation (2) to determine n_1, $\phi_{n_1}(T_1)$, n_2, $\phi_{n_2}(T_2)$ and then proceed recursively.

The value of n_1 is obtained from $b_1, \ldots, b_{n-1}$ by noting that n_1 is the largest interger less than or equal to n/2 such that

$$\sum_{\nu=1}^{n_1-1} b_\nu b_{n-\nu} \leq r,$$

and $n_1 + n_2 = n$ gives n_2.

If $n_1 < n/2$, $\phi_{n_1}(T_1)$ and $\phi_{n_2}(T_2)$ may be obtained by computing the quotient and remainder of

$$r - \sum_{\nu=1}^{n_1-1} b_\nu b_{n-\nu} \text{ and } b_{n_1}.$$

Suppose that $n_1 = n_2 = n/2$. The problem is to find integers x, y such that

(3) $0 \leq x \leq y \leq b_{n/2}-1$

and

(4) $r = \sum_{\nu=1}^{n/2-1} b_\nu b_{n-\nu} + x b_{n/2} - \frac{1}{2}x(x+1) + y.$

Let x_o, y_o be the solutions, and let $F(x) = xb_{n/2} - \frac{1}{2}x(x+1)$; then $F(x)$ is increasing for $0 \leq x \leq b_{n/2}-1$. It follows that if x_1, y_1 also solve equation (4), if $x_1 < x_o$, $y_1 \geq b_{n/2}$; and if $x_1 > x_o$ then $y_1 < 0$. Thus

$$x_o = \max \{\text{integers } b_{n/2} : F(x) \leq r - \sum_{\nu=1}^{n/2-1} b_\nu b_{n-\nu}\},$$

$\phi_{n/2}(T_1) = x_o$ and $\phi_{n/2}(T_2) = y_o$.

So in either case $n_1, \phi_{n_1}(T_1)$, n_2, and $\phi_{n_2}(T_2)$ can be determined from equation (2), and the unranking function can be computed recursively.

Again, a question arises: how difficulty is it to compute the unranking function?

Theorem 3: Computation of the unranking function is at most $0(n^2)$. Exclusive of calculating $b_1, \ldots, b_{n-1}$, computation of the unranking function is, in the worst case, $0(n \log n)$ where the logarithm is to the base 2.

Proof: The $0(n^2)$ part of the theorem follows as in Theorem 2.

Suppose that $b_1, \ldots, b_{n-1}$ are known, and let $t(n)$ denote the number of operations to unrank r, $0 \leq r \leq b_n - 1$, in the worst case.

If $n_1 < n/2$, $t(n)$ satisfies the recurrence

$$t(m) = \max_{1 \leq n \leq n/2} \{ t(n_1) + t(n_2) + 0(n_1) \}.$$

If $n_1 = n/2$, the method used to determine x_o, y_o must be taken into account. By using binary search, x_o may be determined in $0(\log b_{n/2})$ comparisons, where the logarithm is to the base 2 [6]. Now

$$b_n \leq \frac{1}{n}\binom{2n-2}{n-1}$$

since the right side is the number of ordered binary trees with n leaves [4]; using Stirling's approximation, b_n is bounded: $b_n \leq 0(4^n)$. So it requires $0(n)$ comparisons to compute x_o; but $n_1=n/2$, so in the case $n_1=n/2$, $t(n) = 2t(n/2) + 0(n/2)$.

Hence

$$t(n) = \max_{1 \leq n_1 \leq n/2} \{ t(n_1) + t(n_2) + 0(n_1) \},$$

and the argument of Theorem 2 shows that $t(n) = 0(n \log n)$.

APPLICATIONS

There are two applications of this work which are readily apparent: random generation of unordered binary trees, and isomorph rejection of ordered binary trees.

To construct an n-leaf unordered binary tree at random it is necessary only to choose an integer r, $0 \leq r \leq b_n - 1$, at random and apply the unranking algorithm.

Regarding isomorph rejection of ordered binary trees: each n-leaf unordered binary tree represents a class of isomorphic n-leaf ordered binary trees; so generation of all unordered n-leaf binary trees will generate precisely one representative of each isomorphism class of ordered trees; this can be accomplished by applying the unranking function to the integers 0, 1, ..., $b_n - 1$ in succession.

There is a linear time isomorphism algorithm for ordered trees; so the isomorph rejection of ordered binary trees may be accomplished by generating all ordered binary trees with n leaves and, as each new tree is generated testing it for isomorphism to all representatives generated up to that point, retaining the new tree if and only if it is not isomorphic to any previously generated representatives.

Isomorph rejection using the unranking function for unordered binary trees requires $0(n \log n\, b_n)$ steps to generate the representatives; the method based on isomorphism testing requires at least $0(n\, b_n^2)$ steps.

Figure 1

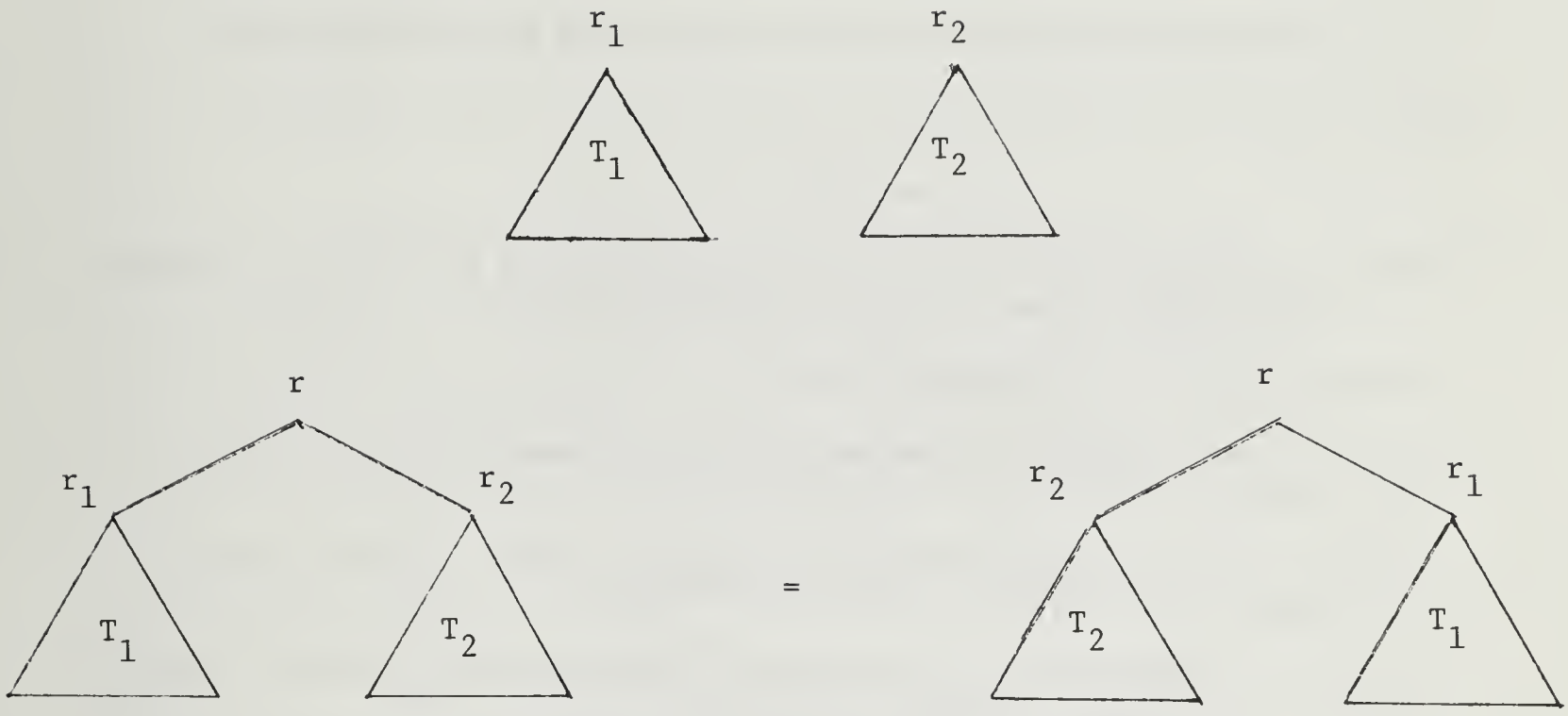
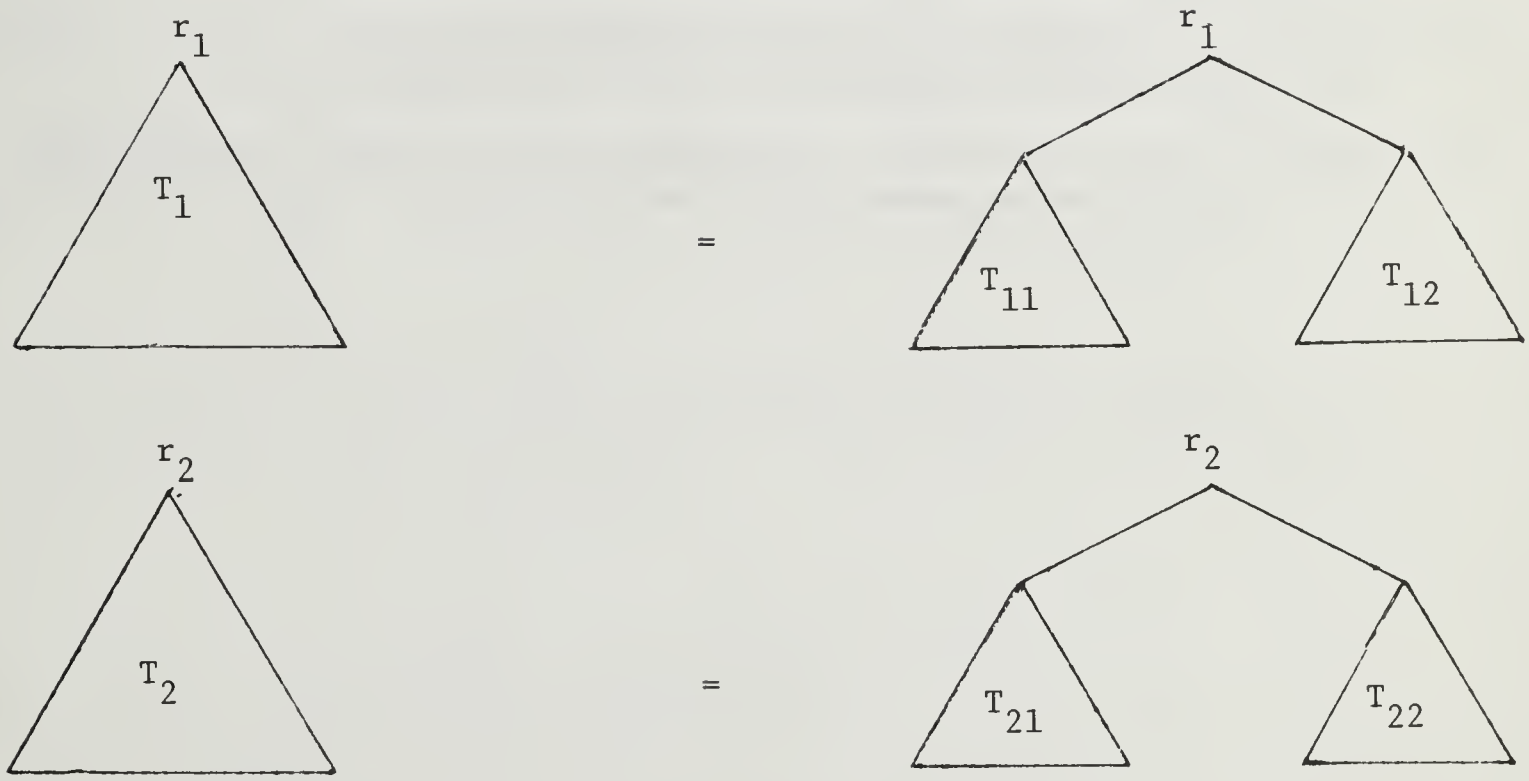


Figure 2



By neglecting the $\frac{1}{2}\ b_n$ which occurs in the n even case in equation (1) and using generating functions it can be shown that $b_n \geq O(2^n)$. Thus isomorph rejection by using the unranking function is more efficient.

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AN N-POINT PROBLEM FOR A QUASI-LINEAR DIFFERENTIAL EQUATION.

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ABSTRACT. The author first proves an n-point boundary problem for a non-homogeneous, almost linear, nth order differential equation, based on the behavior of the associated homogeneous equation. Using this result, one can readily determine conditions on the equation

$$\frac{d^2x}{dt^2} + a_2(t)\ \frac{dx}{dt} + a_1(t)\ x = 0$$

so that $\frac{d^2x}{dt^2} + a_2(t)\ \frac{dx}{dt} + a_1(t)\ x = \mu\ f\ (t,\ x,\ \frac{dx}{dt}\ ,\ \mu)$

has a unique solution through two points of its domain.

INTRODUCTION

In his classical treatise Picard (1908,a) discusses the following problem: Let there be given the differential equation

$$\frac{d^2x}{dt^2} = f\ (t,\ x,\ \frac{dx}{dt}\ ,\ \mu)\ , \qquad (1)$$

where f is continuous in t and analytic in x, $\frac{dx}{dt}$, and μ. Suppose for $\mu = 0$, there is a solution of (1), defined over a closed interval [a,b] and taking the values $x = A$ for $t = a$ and $x = B$ for $t = b$. Does there exist, for $|\mu|$ small, an integral of (1) taking the same initial and terminal values and differing little from the given solution? That such an integral may not exist is seen by considering the linear equation

$$\frac{d^2x}{dt^2} + k\ P\ (t)\ x = 0\ , \qquad (2)$$

where P is positive and continuous over an interval containing $t = a$ and $t = b$, $b > a$. Let k be chosen so that the solution of (2) satisfies $x(a) = 0$ and $x(b) = 0$. Then if $|\mu|$ is sufficiently small, but not zero, the equation

$$\frac{d^2x}{dt^2} + (k + \mu)\, P(t)\, x = 0 \qquad (3)$$

has no non-trivial solution satisfying $x(a) = x(b) = 0$. Using his successive approximation theory, Picard cites the following existence and uniqueness criterion concerning (1): For all μ in a small neighborhood of zero, let $(t, x, \frac{dx}{dt})$ be in a domain of $(t, x, \frac{dx}{dt})$-space for which the hypotheses of the successive approximation theorem is valid. Then, for b-a sufficiently small, together with a suitable Lipschitz condition, a unique solution taking the required values is assured.

It turns out that for certain "almost linear" equations, one need not use a Picard scheme of successive approximations at all; instead, it is sufficient to use standard theory for linear equations, together with the implicit function theorem. In the course of proving our first theorem, we will use the Poincaré Expansion Theorem (Lefschetz, 1957). This may be stated as follows: Consider the system

$$\frac{d\vec{x}}{dt} = \vec{X}(\vec{x}, t, \mu)$$

where t is real and $\vec{X}$ is analytic in some domain of $(\vec{x}, t, \mu)$-space. Suppose for $\mu = 0$, the system has a solution $\vec{\ell}(t)$ on the closed interval $I = [t_1, t_n]$ such that for fixed t the X_i may be expanded in power series of $(x_i - \ell_i)$ and μ, uniformly convergent in some region $\| \vec{x} - \vec{\ell} \| < \alpha$, $\| \mu \| < \alpha$, $t \in I$. Then, setting $\vec{\ell}(t_i) = \vec{A}_1^{(i-1)}$, $i = 1, \ldots, n$, the system has a solution $\vec{x}(t, \vec{\lambda}, \mu)$ such that $\vec{x}(t, \vec{A}_1, 0) = \ell(t)$ and for fixed t, the $\vec{x}_i(t, \vec{\lambda}, \mu)$ may be expanded in power series of the $(\vec{\lambda} - \vec{A}_1)$ and μ convergent for $t \in I$ and $\| \vec{\lambda} - \vec{A}_1 \| < \beta$, $\| \mu \| < \beta$.

THE BASIC THEOREM

We begin with the equation

$$x^{(n)} + a_n(t)\, x^{(n-1)} + \ldots + a_1(t)\, x = \mu\, f[t, x, x^1, \ldots, {}^{(n-1)}, \mu] \qquad (4)$$

where $x^{(i)} = \frac{d^i x}{dt^i}$ and $n \geq 2$. It is assumed that the coefficients $a_i(t)$ are continuous and that f is continuous in t and analytic in $\mu, x, x^1, \ldots, x^{(n-1)}$ in some domain D of Euclidean (n+2)-dimensional space.

Theorem 1: If for $\mu = 0$, (4) has a unique solution $x = \ell(t)$ satisfying $\ell(t_i) = A_i$, $i=1, \ldots, n$ and $t_i < t_{i+1}$ then for $|\mu|$ sufficiently small, there exists a unique solution $\Psi(t)$ of (4), passing through the same points (t_i, A_i) and satisfying $|\ell - \Psi| < \eta$, where $\eta \to 0$ with μ.

Proof: Let us first write (4) in the form of the equivalent system

$$\frac{dx_i}{dt} = x_{i+1}$$
$$\frac{dx_n}{dt} = -\sum_{j=1}^{n} a_j(t)\, x_j + \mu\, f(t, x_1, \ldots, x_n, \mu), \qquad (5)$$

where $i = 1, \ldots, n-1$ and $x \equiv x_1$. For $\mu = 0$, (5) admits a unique solution $x_i = \ell^{(i-1)}(t)$ such that $\ell^{(i-1)}(t_1) = A_1^{(i-1)}$ and $A_1^{(0)} \equiv A_1$. According to the Poincaré Expansion Theorem, there exists a unique solution of (5) given by

$$x_i = x_i(t, \lambda_0, \lambda_1, \ldots, \lambda_{n-1}, \mu), \qquad (6)$$

where $x_i(t_1, \lambda_0, \ldots, \lambda_{n-1}, \mu) = \lambda_{i-1}$. The x_i are expandable in a series of powers of $(\lambda_{i-1} - A_1^{(i-1)})$ and μ with coefficients continuous in t. The expansion is valid on the domain of $(\mu, t, \vec{\lambda})$ defined by

$\sum_{i=1}^{n} |\lambda_{i-1} - A_1^{(i-1)}| < \delta$, $|\mu| < \delta$, and $t \in [t_1, t_n]$, where $\delta > 0$ and generally small. For $\lambda_{i-1} = A_1^{(i-1)}$ and $\mu = 0$, the solution (6) reduces to $\ell^{(i-1)}(t)$. If we now substitute the x_i of (6) into $f(t, x_1, \ldots, x_n, \mu)$ of (5) and use the variation of parameters formula, the solution $x = x_1$ of (5) satisfying $x(t_1) = A_1$ can be written as

$$x(t, A_1, \lambda_1, \ldots, \lambda_{n-1}, \mu) = y(t, A_1, \lambda_1, \ldots, \lambda_{n-1}) +$$
$$\mu \sum_{j=1}^{n} Z_j(t) \int_{t_1}^{t} \frac{W_j[Z_1(s), \ldots, Z_n(s)]}{W[Z_1(s), \ldots, Z_n(s)]}\, f[s, x_1(s), \ldots, x_n(s), \mu]\, ds \qquad (7)$$

where

i) The Z_j are a fundamental set for the homogeneous system associated with (5) and the Wronskian $W[Z_1(t_1), \ldots, Z_n(t_1)]$ is the determinant with ones on the diagonal and zeroes elsewhere;

ii) $W_j[Z_1, \ldots, Z_n]$ is the determinant obtained by replacing the jth column of $W[Z_1, \ldots, Z_n]$ by col $(0, 0, \ldots, 0, 1)$;

iii) $y(t, A_1, \lambda_1, \ldots, \lambda_{n-1})$ is the solution of (5) for $\mu = 0$ such that $y(t_1) = A_1$, $y^1(t_1) = \lambda_1$, $\ldots$, $y^{(n-1)}(t_1) = \lambda_{n-1}$.

The solution (7) must satisfy the system

$$F_i \equiv x(t_{i+1}) - A_{i+1} = 0 \qquad (8)$$

for $i = 1, \ldots, n-1$. Clearly, the F_i depend on the λ_i and μ.

It is evident that for $\mu = 0$ and $(\lambda_1, \ldots, \lambda_{n-1}) = (A_1^{(1)}, \ldots, A_1^{(n-1)})$, equation (8) is satisfied since then $x = \ell(t)$. Thus in order to solve (8) for the λ_i in terms of μ, it is sufficient that the Jacobian

$$\frac{\partial (F_1, \ldots, F_{n-1})}{\partial (\lambda_1, \ldots, \lambda_{n-1})} \neq 0 \text{ at } \mu = 0$$

and $(\lambda_1, \ldots, \lambda_{n-1}) = (A_1^{(1)}, \ldots, A_1^{(n-1)})$.

From (7), with

$$x(t_{i+1}) = y(t_{i+1}) + \mu \sum_{j=1}^{n} Z_j(t_{i+1}) \int_{t_1}^{t_{i+1}} \frac{W_j}{W} f \, ds$$

and

$$y(t_{i+1}) = A_1 Z_1(t_{i+1}) + \lambda_1 Z_2(t_{i+1}) + \ldots + \lambda_{n-1} Z_n(t_{i+1}),$$

the Jacobian is the determinant

$$\begin{vmatrix} Z_2(t_2) & Z_3(t_2) & \cdot & \cdot & \cdot & Z_n(t_2) \\ Z_2(t_3) & Z_3(t_3) & \cdot & \cdot & \cdot & Z_n(t_3) \\ \cdot & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot \\ Z_2(t_n) & Z_3(t_n) & \cdot & \cdot & \cdot & Z_n(t_n) \end{vmatrix} \tag{9}$$

But ℓ is unique through the points A_i so that the system

$$\sum_{j=1}^{n} c_j Z_j(t_i) = A_i, \quad i = 1, 2, \ldots, n,$$

must have a non-vanishing determinant. This determinant is

$$\begin{vmatrix} 1 & 0 & \cdot & \cdot & \cdot & 0 \\ Z_1(t_2) & Z_2(t_2) & \cdot & \cdot & \cdot & Z_n(t_2) \\ \cdot & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot \\ Z_1(t_n) & Z_2(t_n) & \cdot & \cdot & \cdot & Z_n(t_n) \end{vmatrix},$$

which is equal to (9). Thus, the Jacobian does not vanish at the given point. This implies that for $|\mu|$ small, we can determine unique values $\lambda_1, \ldots, \lambda_{n-1}$ so that the solution $\Psi(t)$ of (5) exists and passes through the desired points. Moreover, as is evident from the expansion properties, $|\ell - \Psi|$ depends on the magnitude of μ. q.e.d.

AN APPLICATION

There is a direct application of Theorem 1 to the equation

$$\frac{d^2x}{dt^2} + a_2(t)\ \frac{dx}{dt} + a_1(t)\ x = \mu\ f\ (t,\ x,\ \frac{dx}{dt}\ ,\ \mu).$$

Theorem 2. Let $Z_1(t)$ and $Z_2(t)$ be solutions of $\frac{d^2x}{dt^2} + a_2(t)\ \frac{dx}{dt}$

$$+ a_1(t)\ x = 0, \qquad (11)$$

where $Z_1(t_1) = 1$, $\frac{dZ_1}{dt}\ (t_1) = 0$, $Z_2(t_1) = 0$,

and $\frac{dZ_2}{dt}\ (t_1) = 1$.

If $-4a_1 > a_2^2$ for all $t \in [t_1, t_2]$ then (11) has a unique solution $\ell(t)$, satisfying $\ell(t_1) = A_1$ and $\ell(t_2) = A_2$.

Proof: We can write $\ell(t) = c_1Z_1 + c_2Z_2$ so that the pair of equations

$$\ell(t_1) = c_1Z_1\ (t_1) + c_2Z_2\ (t_1) = A_1,$$

$$\ell(t_2) = c_1Z_1\ (t_2) + c_2Z_2\ (t_2) = A_2$$

must be satisfied. Since $Z_1(t_1) = 1$ and $Z_2\ (t_1) = 0$, $c_1 = A_1$. It remains to choose c_2 so that $c_2Z_2\ (t_2) = A_2 - A_1Z_1\ (t_2)$. Obviously, there is a unique way to do this if $Z_2(t_2) \neq 0$. We will use a technique due to Picard (1908,b) to show that this is so. Now,

$$\int_{t_1}^{t_2} Z_2\ \left(\frac{d^2Z_2}{dt^2} + a_2\frac{dZ_2}{dt} + a_1Z_2\right)\ dt = 0 \qquad (12)$$

since Z_2 satisfies (11). If $Z_2(t_2) = 0$, then integration by parts gives

$$\int_{t_1}^{t_2} Z_2\ \frac{d^2Z_2}{dt^2}\ dt = -\int_{t_1}^{t_2} \left(\frac{dZ_2}{dt}\right)^2\ dt.$$

Thus, (12) can be rewritten as

$$\int_{t_1}^{t_2} \left[\left(\frac{dZ_2}{dt} \right)^2 - a_2 Z_2 \frac{dZ_2}{dt} - a_1 (z_2)^2 \right] dt = 0 \qquad (13)$$

Our hypothesis implies that the integrand in (13) is positive definite so that (13) can be satisfied only if $Z_2 \equiv 0$. But this contradicts linear independence. q.ε.d.

From Theorems 1 and 2, it is clear that if $-4a_1 > (a_2)^2$ for all $t \in (t_1, t_2]$, equation (10) always has a unique solution through any points of its domain.

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SOME RECENT RESULTS IN THE THEORY OF POLYGENIC FUNCTIONS OF A COMPLEX VARIABLE

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ABSTRACT. A discussion and summary is given of some recent results in the theory of non-analytic (polygenic) functions. Examples of the strict ordering of the various classes of polygenic functions are given. A generalization of the characteristic properties of the first derivative to a more general derivative is given. Some results concerning the scale ellipse of a cartogram and the Kasner derivative circle are included.

INTRODUCTION

There are a number of ways to generalize the concept of an analytic function. The largest amount of most recent work has been done by Bers (1953) and Vekua (1962). The direction to be followed here is due to Kasner (1927) who introduced the concept of a polygenic function, and was the original line of development in the subject. Some recent results of the author will be given in this paper.

A polygenic function

$$w = f(z) = u + iv = u(x,y) + iv(x,y),$$

is a finite, complex, single-valued function of $z = x + iy$, defined on a bounded domain S of the complex z-plane such that each of the two real component functions $u = u(x,y)$, and $v = v(x,y)$, is continuous and possesses continuous partial derivatives of at least the first order with respect to x and y, everywhere on S.

In S, let $z + \Delta z$ approach the fixed point z along any given regular curve C. Then the first derivative $\gamma = dw/dz$, of $w = f(z)$, with respect to z, is

$$\gamma = \frac{dw}{dz} = \frac{\partial w}{\partial z} + \frac{\partial w}{\partial \bar{z}} e^{-2i\theta},$$

where the mean derivative $\partial w/\partial z$ and the phase derivative $\partial w/\partial \bar{z}$ are defined by the relations

$$\frac{\partial w}{\partial z} = \frac{1}{2}\left(\frac{\partial w}{\partial x} - i\frac{\partial w}{\partial y}\right) = \frac{1}{2}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + \frac{i}{2}\left(-\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right),$$

$$\frac{\partial w}{\partial \bar{z}} = \frac{1}{2}\left(\frac{\partial w}{\partial x} + i\frac{\partial w}{\partial y}\right) = \frac{1}{2}\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right) + \frac{i}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right).$$

and θ is an angle of inclination of the tangent line to the regular curve C at the fixed point z.

In general, there is a one-parameter family of values of the derivative of a polygenic function at each given point. Thus, in general, a polygenic function is a non-analytic function. A polygenic function reduces to a monogenic or holomorphic function at a point if and only if the phase derivative is zero there.

CLASSES OF POLYGENIC FUNCTIONS

A polygenic function $w = f(z)$, is said to be of class n, $n \geq 1$, on S if and only if it is continuous and possesses continuous partial derivatives with respect to x and y of all orders k, $1 \leq k \leq n$, everywhere on S.

The class C^n, $n \geq 1$, is the set of all polygenic functions, each of which is of at least class n on some bounded domain S of the complex z-plane.

The class C^0 is the set of all continuous complex functions defined on some bounded domain S of the complex z-plane.

A polygenic function $w = f(z)$, is said to be of class ∞ on S if and only if, for every natural number n, $n \geq 1$, the function is of class n on A.

The class C^∞ is the set of all polygenic functions, each of which is of class ∞ on some bounded domain S of the complex z-plane.

A polygenic function $w = f(z)$, is said to be of class ω on S if and only if, for each point $c = a + bi$, in S, there is some neighborhood $N(c,r)$ such that whenever $z = x + iy$, is in $N(c,r)$, then the two real component functions $u = u(x,y)$, and $v = v(x,y)$, can be represented by a convergent Taylor series in $(x - a)$ and $(y - b)$.

The class C^ω is the set of all polygenic functions, each of which is of class ω on some bounded domain S of the complex z-plane.

The strict ordering, by inclusion of the various classes, namely,

$$C^0 \supset C^1 \supset C^2 \supset \cdots \supset C^n \supset C^{n+1} \supset \cdots \supset C^\infty \supset C^\omega \qquad (1)$$

may be established in the following manner.

Consider the example, due to Weiersterss, of a real, everywhere continuous function which is nowhere differentiable, namely,

$$g_o(x) = \sum_{n=o}^{\infty} b^n \cos(a^n \pi x),$$

where $o<b<1$, $a \geqslant 1$, is a real, odd, positive integer, and $ab>1 + (3\pi/2)$.

Set

$$g_n(x) = \int_0^x g_{n-1}(t)dt, \quad n \geqslant 1.$$

Then the function

$$f_n(z) = g_n(x) + ig_n(y), \quad n \geqslant o.$$

with $z = x + iy$, is of class $n \geqslant o$, and is <u>not</u> of class $(n + 1) \geqslant 1$.

The final inclusion, $C^{\infty} \supset C^{\omega}$, may be established as follows.

Let $\{n_i\}$ be a sequence of non-negative integers defined by the recursion relations

$$n_o = 0, \; n_{i+1} = 2^{n_i}, \; i = 0,1,2,\cdots$$

For each positive integer n, let $U_n(x)$ be the <u>n - th Tchebycheff polynomial of the first kind</u>, namely,

$$U_n(x) = \cos n\theta, \; x = \cos \theta, \text{ for all } x \text{ in the closed interval } [-1,1].$$

The <u>Cartan function C(x)</u> is the real function

$$C(x) = \sum_{i=1}^{\infty} 2^{-2n_i^2} U_{n_{i+1}}(x), \quad -1 \leqslant x \leqslant 1,$$

introduced by H. Cartan (1940). Cartan showed that C(x) is of class ∞ on [-1,1]. Furthermore, he showed that C(x) is <u>not</u> analytic at any point of the closed interval [-1,1]. Details of these results may be found in Johnson (1973).

Now consider an open region S of the complex z-plane such that whenever $z = x + iy$, is in S, the conditions $-1 \leqslant x \leqslant 1$, and $-1 \leqslant y \leqslant 1$, are valid. Consider the polygenic function h(z) defined on S by the relation

$$h(z) = C(x) + iC(y),$$

where C(x) and C(y) denote the Cartan function described above. It is immediate that h(z) is of class ∞ on S. Furthermore, h(z) fails to be analytic at each point z in S.

We summarize the above remarks in Theorem 1: The various classes C^n, $n = 0,1,2,3,\ldots,\infty,\omega$, of polygenic functions form a strictly decreasing sequence relative to set inclusion.

PROPERTIES OF THE DERIVATIVE

The second topic of discussion will concern the derivative of a polygenic function with respect to another polygenic function. Before doing so, it will be useful to summarize again the case of the ordinary first derivative of a polygenic function.

It is standard practice to use the complex z-plane, with $z = x + iy$, and the complex w-plane, with $w = u + iv$, in the study of complex functions $w = f(z)$. In the study of polygenic functions $w = f(z)$, it is convenient to introduce a third plane, the complex γ-plane, where $\gamma = \alpha + i\beta$, termed the derivative plane. Thus,

$$\gamma = \alpha + i\beta = \frac{dw}{dz} = \frac{\partial w}{\partial z} + \frac{\partial w}{\partial \bar{z}} e^{-2i\theta} .$$

The derivative of a polygenic function may then be represented by a locus of points in the derivative plane.

Kasner (1936) showed that the derivative of a polygenic function possesses the following three characteristic properties.

Property I, the Kasner derivative circle. At each fixed point z in S the set of inclinations θ at z is mapped onto a circle, termed the Kasner derivative circle, in the derivative plane. From the formula for γ, above, we see that the circle is given by

$$|\gamma - \frac{\partial w}{\partial z}| = |\frac{\partial w}{\partial \bar{z}}| .$$

The center of the Kasner derivative circle is given by the mean derivative $\partial w/\partial z$ of $w = f(z)$, and the radius is given by the modulus of the phase derivative $\partial w/\partial \bar{z}$ of $w=f(z)$.

The Kasner derivative circle has many interesting properties, both geometric and analytical. See, for example, Johnson (1973).

Property II, the -2:1 ratio. If the inclination θ at z changes at a constant rate, the corresponding point $\gamma = \alpha + i\beta$, on the Kasner derivative circle traverses that circle in the opposite direction at a constant rate which is twice that of θ, provided that the phase derivative is not zero.

It is necessary to introduce some additional terminology before discussing the third property of the derivative.

The oriented circle described by Properties I and II is an example of a clock; in particular, a uniform clock, because of the constant ratio -2:1.

If the polygenic function $w = f(z)$, is of at least class 2 on S, then the derivative may be considered a special case of the general clock transformation

$$\gamma = A(z) + B(z)e^{-2i\theta} , \tag{2}$$

where $A(z)$ and $B(z)$ are polygenic functions, each defined on S.

The set of points $\gamma = \alpha + i\beta$, described by (2) is termed a clock. The center of the clock is $A(z)$ and the phase point of the clock is $A(z) + B(z)$, that is, the point which corresponds to the inclination $\theta = 0$, at z.

To the clock described by (2), we may associate the central clock described by the transformation

$$\gamma = \frac{\partial A}{\partial z} + \frac{\partial A}{\partial \bar{z}} e^{-2i\theta} ,$$

and the phase-point clock described by the transformation

$$\gamma = \left(\frac{\partial A}{\partial z} + \frac{\partial B}{\partial z}\right) + \left(\frac{\partial A}{\partial \bar{z}} + \frac{\partial B}{\partial \bar{z}}\right) e^{-2i\theta} .$$

Property III. For a polygenic function of at least class 2, the center of the phase-point clock coincides with the phase point of the central clock.

If (2) is the derivative of a polygenic function $w = f(z)$, so that $A(z) = \partial w/\partial z$, and $B(z) = \partial w/\partial \bar{z}$, it is easy to show that the center of the phase-point clock coincides with the phase-point of the central clock.

Conversely, if we begin with the general transformation

$$\gamma = \gamma_1 (z,\theta) + i\gamma_2 (z,\theta),$$

Properties I, II, and III are sufficient conditions that the transformation represents the derivative of some polygenic function $w = f(z)$. The original proof is in Kasner (1936).

We now consider a generalization of the situation just described.

Consider two polygenic functions

$$W = G(z) = U + iV = U(x,y) + iV(x,y),$$
$$Z = F(z) = X + iY = X(x,y) + iY(x,y),$$

each defined on the same bounded domain S of the complex z-plane.

Let z be a fixed but arbitrary point in S such that $\partial Z/\partial z$ and $\partial Z/\partial \bar{z}$ are not both zero. Let C be a regular curve of approach to z whose tangent at z has an angle θ of inclination. Then the first derivative $\gamma = dW/dZ$, of $W = G(z)$, relative to $Z = F(z)$, is

$$\gamma = \frac{dW}{dZ} = \frac{\frac{\partial W}{\partial z} + \frac{\partial W}{\partial \bar{z}} e^{-2i\theta}}{\frac{\partial Z}{\partial z} + \frac{\partial Z}{\partial \bar{z}} e^{-2i\theta}}$$

The ordinary derivative dW/dz is obtained by sitting Z = z.

At a given fixed point z in the complex z- plane, a homographic clock is the image under a map defined on the set of all inclinations θ through z into the derivative plane such that the image of the map is either a point, a line, or a proper circle. This is termed Property I of homographic clocks, and is the direct generalization of Property I for the ordinary derivative $\gamma = dw/dz$, of a polygenic function $w = f(z)$.

Property II of homographic clocks is the condition that the cross-ratio of every four distinct inclinations through z is converted into the same cross-ratio as that of the four distinct image points in the derivate plane. This generalizes Property II of the ordinary derivative $\gamma = dw/dz$, of a polygenic function $w = f(z)$.

Properties I, and II imply that such a homographic clock is described by the complex parametric equation

$$\gamma = \frac{A+Be^{-2i\theta}}{C+De^{-2i\theta}} \quad ,$$

where A, B, C, D are four complex constants with C and D not both zero.

In general, we may consider a congruence of homographic clocks, namely,

$$\gamma = \frac{A(z)+B(z)e^{-2i\theta}}{C(z)+D(z)e^{-2i\theta}} \quad , \tag{3}$$

defined at each point z in S. Here A(z), B(z), C(z), and D(z) are polygenic functions of at least class two on the simply connected open region S. Furthermore, it is assumed that the Jacobian

$$J = A(z)\cdot D(z) - B(z)\cdot C(z) \neq 0,$$

everywhere on S.

The congruence of clocks (3) represents the derivative of some polygenic function W = G(z), relative to some polygenic function Z = F(z), each of which is of at least class three on S, if and only if

$$\frac{\partial}{\partial z}\left[\frac{A\left(\frac{\partial C}{\partial \bar{z}} - \frac{\partial D}{\partial z}\right) + C\left(\frac{\partial B}{\partial z} - \frac{\partial A}{\partial \bar{z}}\right)}{J}\right] - \frac{\partial}{\partial \bar{z}}\left[\frac{B\left(\frac{\partial C}{\partial \bar{z}} - \frac{\partial D}{\partial z}\right) + D\left(\frac{\partial B}{\partial \bar{z}} - \frac{\partial A}{\partial \bar{z}}\right)}{J}\right] = 0, \tag{4}$$

everywhere on S. The condition (4) is termed Property III for homographic

clocks. By setting C = 1, and D = 0, it can be verified that (4) is a generalization of Property III for the ordinary derivative $\gamma = dw/dz$, of a polygenic function $w = f(z)$.

The above properties were given by DeCicco and Walvekar (1969) without proof. Proofs may be found in Johnson (1973).

In summary, we have Theorem 2: The three characteristic properties of the ordinary derivative dw/dz of a polygenic gunction $w = f(z)$, have direct generalizations to the derivative dW/dZ of a polygenic function $W = G(z)$ with respect to a polygenic function $z = F(z)$.

CARTOGRAMS

Consider a non-degenerate polygenic map T given by

$$w = f(z) = u + iv = u(x,y) + iv(x,y),$$

$$\overline{w} = \overline{f(z)} = u - iv = u(x,y) - iv(x,y),$$

defined on a bounded domain S of the complex z-plane, with Jacobian

$$J = \frac{\partial(u,v)}{\partial(x,y)} = \frac{\partial(w,\overline{w})}{\partial(z,\overline{z})} = \left|\frac{\partial w}{\partial z}\right|^2 - \left|\frac{\partial w}{\partial \overline{z}}\right|^2 \neq 0,$$

everywhere on S.

The scale $r>o$ of a non-degenerate polygenic map T is $r = |dz/dw| > 0$.

A cartogram T is a non-degenerate polygenic map T with scale r, defined above.

In general, the scale r of a cartogram T is a function of position $z = x + iy$, and inclination θ at z.

A point z is termed a focus z relative to a given cartogram T if and only if the scale r is independent of the inclination θ at the point z.

Relative to a given point z in S, set

$$A = \frac{\partial w}{\partial z}\ ,\ B = \frac{\partial w}{\partial \overline{z}}$$

Then, from the relation

$$\frac{1}{r^2} = \frac{dw}{dz}\,\frac{d\overline{w}}{d\overline{z}}$$

it follows that the scale r satisfies the equation

$$(A\overline{A} + B\overline{B})r^2 + A\overline{B}r^2e^{2i\theta} + \overline{A}Br^2e^{-2i\theta} = 1 \qquad (5)$$

On a line through z with inclination θ, let Q(w) be the point r units from z. Then (r, θ) may be regarded as polar coordinates (r,θ) of Q(w) relative to z, where $w = re^{i\theta}$.

In isotropic coordinates $w = re^{i\theta}$, $\bar{w} = re^{-i\theta}$, equation (5) becomes

$$A\bar{B}w^2 = (A\bar{A} + B\bar{B})w\bar{w} + \bar{A}B\bar{w}^2 = 1. \qquad (6)$$

Since the discriminant D of this quadratic form is $D = -J/4<0$, the locus described by (6) is an ellipse.

The ellipse Q given by either (5) or (6) is termed the scale ellipse Q of the cartogram T at the point z. The point z is the center of the scale ellipse Q.

Relative to a given cartogram T, a point z is a focus z if and only if the scale ellipse Q constructed at z is a circle Q.

The main diameter of a Kasner derivative circle is that diameter which is contained in the line through the origin and the center of the circle.

At a given point z in S, the absolute value $|\gamma|$ of the derivative $\gamma = dw/dz$, assumes its absolute maximum and its absolute minimum at the endpoints of the main diameter of the Kasner derivative circle. The lines through z which give rise to these values of $|\gamma|$ are orthogonal.

Setting

$$A = ae^{i\alpha},\ B = be^{i\beta},\ \phi = \theta - \frac{\beta-\alpha}{2},$$

it follows that

$$\gamma = A + Be^{-2i\theta} = e^{i\alpha}(a + be^{-2i\phi}). \qquad (7)$$

Equation (7) may be considered as a correspondence from the scale ellipse Q onto the Kasner derivative circle.

At a non-focal point z of a cartogram T, the scale ellipse Q may be mapped onto the Kasner derivative circle in such a manner that the endpoints of the semi-major and semi-minor axes correspond to the endpoints of the main diameter. The magnitude of the derivative at these points, is $1/r_1$ and k/r_2, respectively, where r_1 and r_2 are the respective semi-major and semi-minor axes of the scale ellipse. Also,

$$k = \begin{cases} +1, & a>b>0, \\ -1, & b>a>0. \end{cases}$$

At a non-focal point z of a cartogram T, the product of the reciprocals of the semi-major and semi-minor axes of the scale ellipse Q is equal to kJ, where J is the Jacobian J of R at the point z.

Proofs of the above results and additional results may be found in Johnson (1973) and De Cicco (1973).

In summary, we have Theorem 3: At each non-focal point z of its domain, a cartogram T determines an ellipse which may be mapped onto the Kasner derivative circle such that the endpoints of the semi-major and semi-minor axes of the ellipse correspond to the endpoints of the main diameter of the Kasner derivative circle.

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AN EXACT ALGORITHM FOR THE SMALL SCALE TRAVELING SALESMAN PROBLEM

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ABSTRACT

This note presents a branch and bound algorithm for the small scale traveling salesman problem. This exact algorithm is designed for hand calculation of the problem and differs from other algorithms in that the cost matrix is arranged in a Row tableau and a Column tableau described in the paper. These tableaux permit the "maximum" bound in the search tree to be computed by inspection, and a mark out process on each tableau automatically blocks subtours. No update tableaux are needed and computations are held to a minimum.

1. INTRODUCTION

The traveling salesman problem is the problem of finding the least possible distance required to visit each of n cities once, beginning and ending with the same city. The irony of this problem is that it is so simple to state yet so difficult to solve. There are $(n - 1)!$ possible tours for n cities, and the intuitive idea of enumerating all possible tours quickly becomes unthinkable.

Most problems in optimization have at least one theoretical property which in the search for optimality reduces the original feasible set to a "smaller" feasible set. It is well known that in elementary calculus the maximum value of a differentiable function occurs among the "smaller" set of domain points for which the derivative is zero. The linear programming problem is another such example. If an optimal solution exists, then the search for optimality is restricted to a "smaller" finite set of basic feasible solutions. However, in the traveling salesman problem there are no theorems that significantly reduce the search for an optimal solution to a "smaller" set. In essence, any algorithm that yields an optimal solution must in some way check every possible tour. It is no surprise to see that most of the literature deals with heuristic algorithms that generate "near optimal" solutions. Nevertheless, there are several exact algorithms. A dynamic programming approach has been used by Held in 1962. Branch and bound algorithms have been discussed by Wagner in 1969 and by Little in 1963. The method presented here is similar to Little's method. The major

difference between the branch and bound algorithm presented here and other branch and bound algorithms is the arrangement of input data into a row tableau and a column tableau. These tableaux permit the "bounds" to be computed by inspection and furthermore, a mark out process described shortly automatically eliminates subtours. Computation is minimal as these two tableaux are the only ones used throughout the algorithm.

It is understood that the n-cities are indexed by $i = 1, 2, \ldots, n$. The cost of going from city i to city j is denoted by $c(i, j)$, and $c(i, j)$ need not equal $c(j, i)$. Let $C = [c(i, j)]$ denote the cost matrix. A tour is a set of n ordered cities, $t = \{(i_1, i_2), (i_2, i_3), \ldots, (i_n, i_1)\}$ where the i_j's are distinct, and a tour may be displayed as $i_1 \to i_2 \to \ldots i_n \to i_1$ which indicates that a circuit is formed by going to each city once and only once. The cost of a tour t is denoted by $z(t) = \Sigma\, c(i, j)$, sum taken over all arc (i, j) in t. In general, for any set S of arcs, $(i, j), (r, s), \ldots,$ equate $z(S) = \Sigma\, c(i, j)$, (i, j) in S and $z(S)$ is said to be the cost of the arcs in S. A partial tour is defined to be a set of arcs which can be extended to some tour. In other words, a partial tour is a part of some tour and contains no subtours.

2. THE COST MATRIX

It is well known that if the minimum of arbitrary functions, $f(x)$ and $f(x) + h$ for any real constant h, exists, then the minimum occurs at the same domain point x. Consider the addition of a constant h to any row (or column) of a cost matrix C to form a new matrix C'. Since every tour t selects one entry from each row and each column, the cost $z'(t)$ of tour t relative to matrix C' has the property that $z'(t) = z(t) + h$ where $z(t)$ is the cost of tour t relative to C. Thus, the minimum of $z(t)$ and $z'(t)$ occurs at the same optimal tour t. Summing up, the addition or subtraction of a constant from each entry of a row (or column) of a cost matrix does not alter the optimal tour, just the cost of the tour.

If the smallest entry of a row of a cost matrix is subtracted from all entries of the row, then at least one zero will appear in the row, and this process is called reducing the row. For a given cost matrix C, reduce each row and then analogously reduce each column. The resulting matrix is called a reduced matrix and has the property that its entries are nonnegative and at least one zero appears in each row and each column, see Figure 1. The original problem could be recovered with the additional knowledge of the reducing constants. For each row i of a reduced cost matrix, linear order the entries $c(i_1, j_1), c(i_2, j_2), \ldots, c(i_n, j_n)$. Next, form a row tableau (matrix) whose entries of the i-th row are respectively labeled $j_1c(i_1, j_1), \ldots, j_nc(i_n, j_n)$, see Figure 2. Analogously, form a column tableau. The row tableau and column tableau of a random 7-city problem are shown in Figure 2, and details are explained below.

Notation: We denote row i of the row tableau by Row i; likewise Col. j denotes the j-th column of the column tableau.

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
Row 1		47	75	78	62	87	0
Row 2	0		17	74	54	61	66
Row 3	20	7		1	0	0	43
Row 4	39	51	21		1	0	19
Row 5	8	0	0	44		13	13
Row 6	58	13	40	0	54		28
Row 7	34	0	11	4	59	66	

Figure 1. Reduced Matrix for a 7-city problem

3. A 7-CITY PROBLEM

The purpose of this example is to explain the basic ideas of the algorithm whereas the formal steps will be enumerated in the next section. Figure 1 shows a reduced matrix for a random generated 7-city problem. Note that there is no reason to travel from city i to city i which explains the blanks on the diagonal of the matrix. Next, linear order the entries of Row 1: 0 (Col. 7), 47 (Col. 2), 62 (Col. 5), 75 (Col. 3), 78 (Col. 4), 87 (Col. 6). We point out the arrangement in the Row tableau of Row 1 in Figure 2 places the column number in the center of the cell for quick reference. This column display facilitates the mark out process which will be described shortly. The Row and Col. tableaux are quickly computed.

We keep our attention on Figure 2, and ask what is a lower bound on the cost of all tours that exclude the arc (1, 7)? The answer centers on the fact that city 1 must be connected to a city other than city 7 and some city other than city 1 must connect city 7. For instance, the net cost for using arc (1, 5) and arc (4, 7) in place of arc (1, 7) would be $c(1, 5) + c(4, 7) - c(1, 7) = 62 + 19 - 0 = 81$. The number 81 is a bound for not using arc (1, 7), but we are looking for the lowest such bound. Clearly, the arc (1, 2) and arc (5, 7) yield the lowest bound, due to the linear ordering of the cost of the arcs. Hence, $c(1, 2) + c(7, 5) - c(1, 7) = 47 + 13 - 0 = 60$. Equivalently, the (lowest) bound $= 60 = \min \{c(1, p) + c(k, 7) - c(1, 7) : p \neq 7$

Bounds							
60	Row 1	7 0	2 47	5 62	3 75	4 78	6 87
25	Row 2	1 0	3 17	5 54	6 61	7 66	4 74
$\frac{1}{0}$	Row 3	5 0	6 0	4 1	2 7	1 20	7 43
1	Row 4	6 0	5 1	7 19	3 21	1 39	2 51
$\frac{0}{11}$	Row 5	2 0	3 0	1 8	6 13	7 13	4 44
14	Row 6	4 0	2 13	7 28	3 40	5 44	1 58
4	Row 7	2 0	4 4	3 11	1 34	5 59	6 66

Bounds	25	0|4	11	14	1	0|1	60
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
	2 0	5 0	5 0	6 0	3 0	3 0	1 0
	5 8	7 0	7 11	3 1	4 1	4 0	5 13
	3 20	3 7	2 17	7 4	6 44	5 13	4 19
	7 34	6 13	4 21	5 44	2 54	2 61	6 28
	4 39	1 47	6 40	2 74	7 59	7 66	3 43
	6 58	4 51	1 75	1 78	1 62	1 87	2 66

Figure 2. Row and Column tableaux for a randomly generated 7-city problem

and $k \neq 1\}$ which means that each tour not using arc (1, 7) must have a cost value of at least 60. Again, the linear ordering of the cost of the arcs yields a quick computation of the lowest bound. The other bounds are computed in the same manner, pointing out that a tie in Row 3 causes no problem. If arc (3, 6) is omitted from the tour, then arc (3, 5) and arc (6, 4) can be used and the bound is $c(3, 5) + c(6, 4) - c(3, 6) = 0 + 0 - 0 = 0$. Summing up, the first or second unmarked cell will always contain the information necessary to compute the bounds.

We next search for the largest bound which is 60 and commit its associated arc (1, 7) to our tour. Circle the committed arc (1, 7), that is, circle the 7 in Row 1 and the 1 in Col. 7. In the Row tableau column 7 is no longer eligible as the tail of an arc and thus mark out all 7's in the remaining rows of the Row tableau, and furthermore note that a 7 does not appear in Row 7. This absence of a 7 signals that a subtour must be blocked. We must block (1, 7), (7, 1), and so we mark out 1 in Row 7. Since (1, 7) is committed and Row 1 is used, mark out all 1's in the Column tableau. Again note that no entry is marked out in Col. 1, and this signals that a subtour must be blocked, namely (1, 7), (7, 1). Therefore, we mark out 7 in Col. 1. Remember that one entry must be marked out in each uncommitted row and column. See Figure 3.

Since none of the bounds has been distributed, the maximal bound is 25 and so commit (2, 1) to the tour. Circle 1 in Row 2 and mark out 1 in the remaining uncommitted rows. Remember that one entry must be marked out in each of the uncommitted rows and thus in Row 7, the 1 has been previously marked out. This signals that a subtour must be blocked in this row. From the committed partial tour of (1, 7) and (2, 1) it is seen that the arc (7, 2) can never be used since it would form a subtour of $1 \rightarrow 7 \rightarrow 2 \rightarrow 1$. Therefore, mark out 2 in Row 7. Note that if either of the first two entries of a row or column is marked out, then a change in the bound may occur. Mark out the bound 4 to indicate that it must be undated. For the committed arc (2, 1), in the Column tableau mark out all 2's in the remaining uncommitted columns. Again, we cannot mark out an entry, namely 2, in Col. 2 and recall that the arc(7, 2) must be excluded from consideration as it prevents a subtour, so mark out 7 in Col. 2. Since the marked out 7 in Col. 2 previously served as a bound for Col. 2, mark out the bound $\emptyset|4$. New bounds in Row 7 and Col. 2 are computed.

Some comments on Figure 3 are now in order.

1) The bound for excluding arc (5, 2) is 0 in the Row tableau, yet is 7 in the Column tableau. There is no need to change the bound from 0 to 7 in the Row tableau because we scan both the Row and Column tableaux to locate the arc with the largest bound.

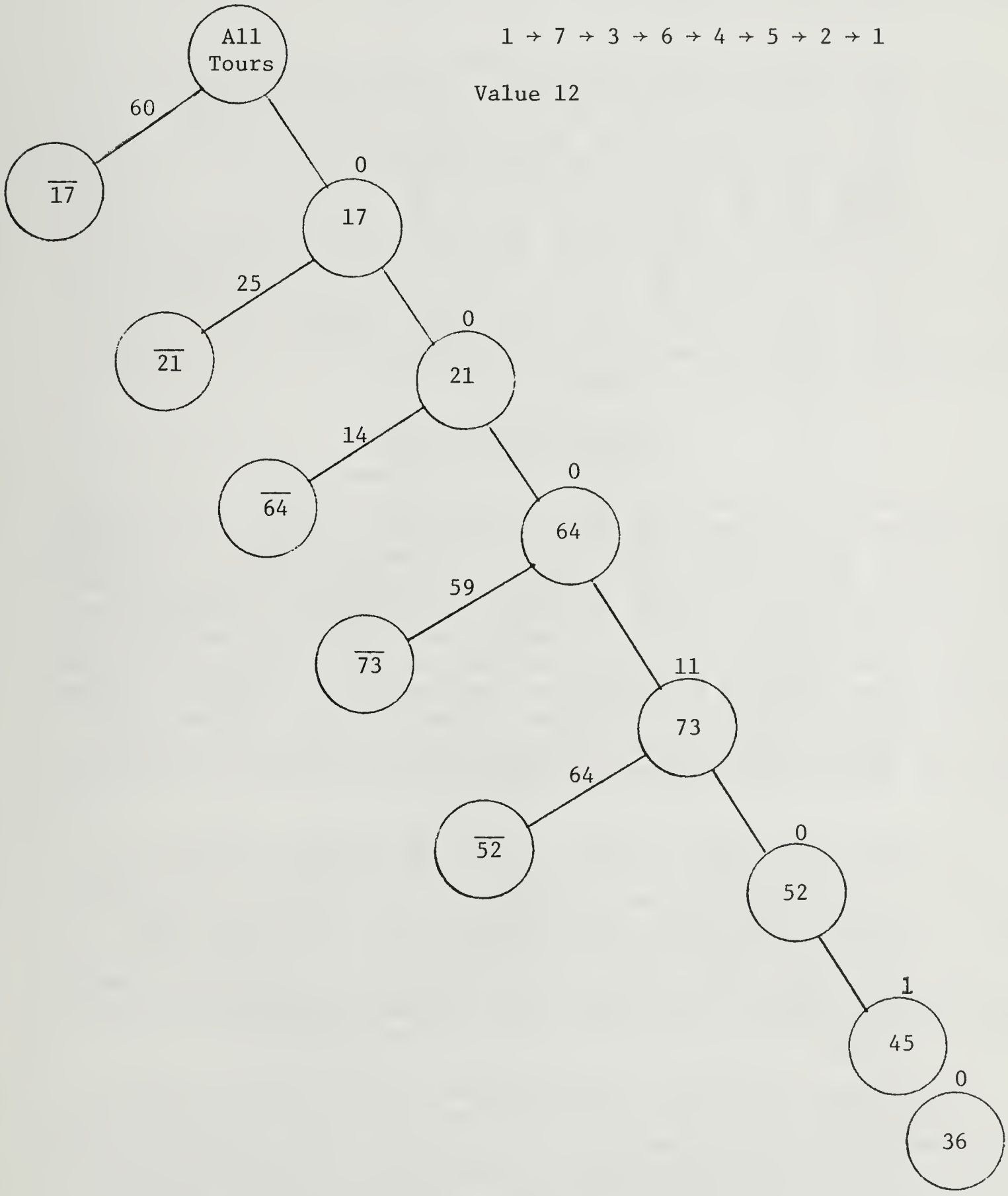
2) In Row 7 it is possible to subtract a 11 from each cost entry. If this were done in Row 7, then there would be a corresponding change of cost entries in the Column tableau which would alter the linear ordering of the cost entries. Hence, the tableau would then be rearranged, which is a time consuming process. The algorithm avoids a reconstruction of the cost matrix at each step. Quickly, the bound in Row 9 is $59 + 0 - 11 = c(7, 5) + c(5, 3) - c(7, 3) = 48$. Note that the first or second unmarked cell will contain information necessary to compute every bound.

Bounds							
(60)	Row 1	(7) 0	2 47	5 62	3 75	4 78	6 87
(25)	Row 2	(1) 0	3 17	5 54	6 61	7/ 66	4 74
1/0	Row 3	5 0	6 0	4X 1	2 7	1* 20	7/ 43
20 X1	Row 4	6X 0	5 1	7/ 19	3 21	1* 39	2 51
0/11	Row 5	2 0	3 0	1* 8	6 13	7/ 13	4X 44
(14)	Row 6	(4) 0	2 13	7/ 28	3 40	5 44	1* 58
48 X7 *4	Row 7	2* 0	4X 4	3 11	1/ 34	5 59	6 66

Bounds	(25)	7 * 0|4	11	(14)	1	13 X 0|1	(60)
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
	(2) 0	5 0	5 0	(6) 0	3 0	3 0	(1) 0
	5 8	7* 0	7 11	3 1	4 1	4X 0	5 13
	3 20	3 7	2* 17	7 4	6X 44	5 13	4 19
	7/ 34	6X 13	4 21	5 44	2* 54	2* 61	6 28
	4 39	1/ 47	6X 40	2* 74	7 59	7 66	3 43
	6 58	4 51	1/ 75	1/ 78	1/ 62	1/ 87	2 66

Figure 3. Tableaux with three mark outs
/ First mark out
* Second mark out
X Third mark out

Figure 4 displays the search tree. We choose to list the cost of arcs and not to keep track of the cost of partial tours. The numbers on



Optimal tour:

$1 \rightarrow 7 \rightarrow 3 \rightarrow 6 \rightarrow 4 \rightarrow 5 \rightarrow 2 \rightarrow 1$

Value 12

Figure 4. Final Search Tree

the branches connecting $\overline{(i, j)}$ is the total cost for not using arc (i, j) in building the tour. The total cost means the bound plus the cost entry of the arc. For instance, the bound for not using $(7, 3)$ turned out to be 48 and the total cost for not using $(7, 3)$ is $c(7, 3) + 48 = 59$. In other words, the total cost is $c(7, 5) + c(5,3) = 59 + 0 = 59$.

The procedure for selecting arcs based on the largest bound yields a final search tree as shown in Figure 4. In case of ties among the largest bound, choose any tying arc. Of course, all branches must be checked, and it is suggested that one work backwards up the tree. Precisely, these five partial tours must be checked: $(1, 7)$, $(2, 1)$, $\overline{(6, 4)}$, $(7, 3)$, $\overline{(5, 2)}$; $\overline{(1, 7)}$, $(2, 1)$, $(6, 4)$, $(7, 3)$; $(1, 7)$, $(2, 1)$, $(6, 4)$; $(1, 7)$, $\overline{(2, 1)}$; $\overline{(1, 7)}$. By checked, it is meant that each above partial tour must be extended until its cost exceeds the cost of the known tour (which is 12 in our example) or until a new tour is formed whose cost is less than 12. Figure 4 shows that any partial tour other than $(1, 7)$, $(2, 1)$, $(6, 4)$, $(7, 3)$, $(5, 2)$, $(4, 5)$, $(3, 6)$ exceeds 12 so it is the optimal tour. The next section shows how any partial tour can be displayed on a Row and Column tableaux.

4. PARTIAL TOUR DISPLAYS

Suppose that the partial tour $(1, 2)$, $(3, 4)$, $\overline{(5, 6)}$ is given and the problem is to extend in an optimal manner this partial tour to a complete tour. The procedure is to display the partial tour on a Row tableau and a Column tableau, and then follow the previous algorithm of Section 4. Circle the arc $(1, 2)$ in the Row tableau and mark out 2 in each uncommitted row, except Row 2 where 1 is marked out to block the subtour $(1, 2)$, $(2, 1)$. Next, circle arc $(3, 4)$, and mark out 4 in each uncommitted row except in Row 4 where 3 is marked out. Next mark out 6 in Row 5. Follow the analogous procedure for the Column tableau and these tableaux are shown in Figure 5. Next, display the partial tour in a tree format as shown in Figure 6 and continue the algorithm as described in the previous section.

We point out a quicker method to arrive at the same tableaux in Figure 5. For the display of $(1, 2)$, $(3, 4)$, $\overline{(5, 6)}$, circle the nodes $(1, 2)$ and $(3, 4)$ in the Row tableau. In the remaining unmarked rows mark out 2 and 4 since these cities (columns) can not be used. Next, $(2, 1)$ and $(4, 3)$ blocks subtours so mark out 1 in Row 2 and 3 in Row 4. Finally, mark out 6 in Row 5. Update the Column tableau in an analogous manner. Clearly, if a partial tour contains many nodes this method would be quicker than the method in the previous paragraph.

For larger problems it is suggested that several copies of the Row and Column tableaux be available to the user. A spirit ditto master or Xerox machine can provide several copies. Suppose that a search tree similar to Figure 4 is formulated and one branch is less than the cost of the tour formed by the algorithm. Then a partial tour can be displayed on an umarked Row tableau and on an unmarked Column tableau. The algorithm continues until a shorter tour is found or until the cost of the

Bounds							
(60)	Row 1	7 0	(2) 47	5 62	3 75	4 78	6 87
37 X 25	Row 2	1/ 0	3 17	5 54	6 61	7 66	4* 74
(1/0)	Row 3	5 0	6 0	(4) 1	2/ 7	1 20	7 43
1	Row 4	6 0	5 1	7 19	3* 21	1 39	2/ 51
19 X 0/11	Row 5	2/ 0	3 0	1 8	6X 13	7 13	4* 44
25 X 14	Row 6	4* 0	2/ 13	7 28	3 40	5 44	1 58
23 X 4	Row 7	2/ 0	4* 4	3 11	1 34	5 59	6 66

Bounds	26 X 25	(0|4)	11	(14)	43 X 1	62 X 0|1	6 X 60
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
	2/ 0	5 0	5 0	6 0	3* 0	3* 0	1/ 0
	5 8	7 0	7 11	(3) 1	4 1	4 0	5 13
	3* 20	3 7	2 17	7 4	6 44	5X 13	4 19
	7 34	6 13	4* 21	5 44	2 54	2 61	6 28
	4 39	(1) 47	6 40	2 74	7 59	7 66	3* 43
	6 58	4 51	1/ 75	1/ 78	1/ 62	1/ 87	2 66

Figure 5. Display of partial tour (1, 2), (3, 4), $\overline{(5, 6)}$

/ First mark out
* Second mark out
X Third mark out

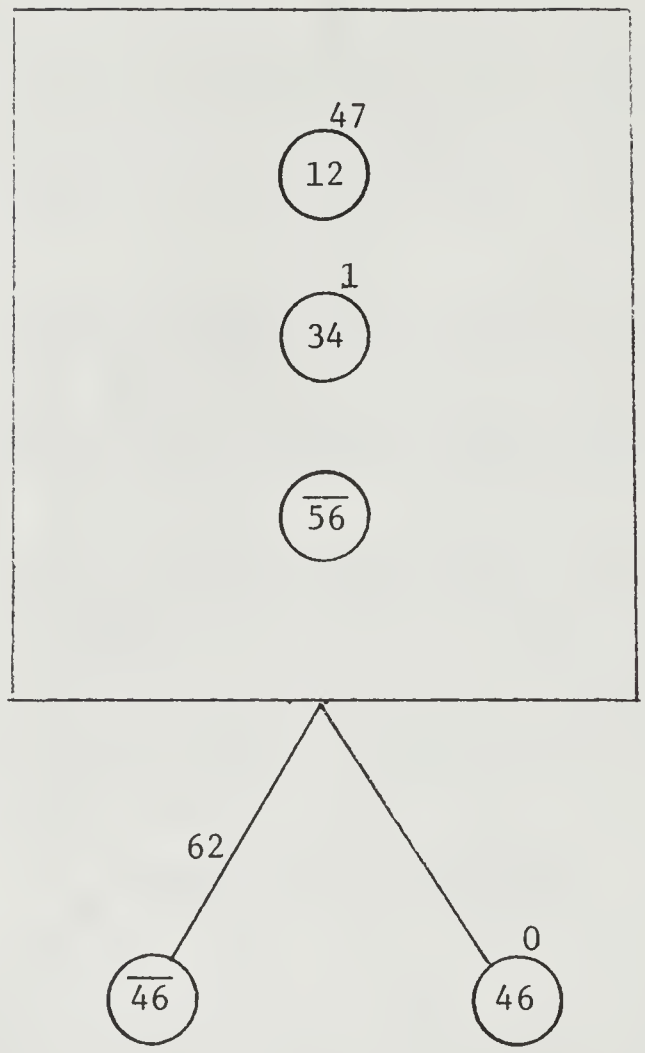


Figure 6. Tree display for (1, 2), (3, 4), $\overline{(5, 6)}$

partial tour exceeds the known shortest tour. Summing up, once copies of the Row tableau and the Column tableau are available, there is practically no additional computation to be made. The linear ordering of the cost entries permit bounds to be quickly observed. Furthermore, partial tours can be quickly updated on new tableaux which aid in checking branches of the search tree.

5. THE ALGORITHM AND FINAL COMMENTS

The algorithm behaves very much like other branch and bound algorithms, and each branch must eventually be checked. For this reason, we merely sketch the algorithm below;

I. Compute bounds and select the branching arc with the largest bound, say (h, k).

Compute bounds on the first entries of each Row and Column and on any entries whose cost equals the cost of the first entries. Place bounds in the bound portion of the tableaux. In case of ties, choose any tying arc. Next circle k in the Row tableau and h in the Column tableau.

II. Record (h, k) in the search tree.

Make two branches, one that extends to (h, k) and the other to $(\overline{h, k})$. Simultaneously, record the cost, c(h, k), above the node, (h, k), and record the bound plus c(h, k) on the branch $(\overline{h, k})$.

III. Update tableaux by a mark out process.

In all eligible rows of the Row tableau mark out all k's and the one row, say p, that contains no k to be marked out will contain an entry q such that (p, q) blocks a subtour. Mark out q. In the Column tableau mark out all h's and in Column q mark out p. Simultaneously, if a first or second entry is marked out, mark out the bound in the corresponding Row or Column. Next, compute bounds if necessary for the uncommitted Rows and Columns.

IV. Return to Step I until a tour is obtained. Then check all branches.

To check branch $(\overline{r, s})$ first find the cost H of the partial from (r, s) to the end of the tour. Branch from $(\overline{r, s})$ until you equal or exceed H or until a new shorter tour is obtained. An alternative to backtracking up the right hand side of the search tree is that one can branch from the lowest bound on the search tree. Theoretically, this lowest branch could lead to a shorter tour.

Since a study on the time required to use the algorithm by hand depends on the problem and on the person's ability to use the algorithm, no special study has been made. However, problems up to and including 12 city problems have been solved in less than one hour. If via Xerox or ditto sheets several copies of the original tableaux are available to help check the branches, the author has found it to be much quicker than other algorithms since practically no calculations are used and no new tableaux are necessary.

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A NEW LOCALITY FOR THE CRAMER(?) MEMBER IN NORTHWESTERN ILLINOIS

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All of the Pennsylvanian marine units in northwestern Illinois are of Desmoinesian age except the poorly fossiliferous and ambiguous Exline Limestone and the clearly Missourian Cramer Limestone. The distribution of the Cramer Limestone is confined to a few small outliers along the ridge that extends generally from Farmington, Fulton County, to Peoria, Peoria County, Illinois. This ridge is underlain by and generally held up by, the Lonsdale Limestone of latest Demoinesian age. Because of its restricted geographic occurrence, probably less than 40 km² in all, known outcrops of the Cramer Limestone are scarce. Wanless (1957,1958) lists no more than four outcrops that are known to include the Cramer, and these apparently exhaust the published references. At Wanless' geologic section 12 (1957:197, UTM 62400189), a limestone was found cropping out in a pasture above the top of the measured section. The Lonsdale at this locality represents an unusual facies for that unit, but its correlation seems relatively secure. The interval between the Lonsdale and this overlying limestone must be at least 20 m, a figure compatible with that separating Londale and Cramer (Wanless, 1958, Fig. 2). Wanless (1957, Pl. 5) does not show rocks as young as Cramer occurring in this area, or indeed, within many kilometers of this locality. Nevertheless, elevations in this area are more or less compatible with those necessary for this outlier to include the Cramer.

The new outcrop is poor and could easly be overlooked. It consists of at least two layers of limestone, each of which has weathered and slumped so that few, if any, of the limestone blocks are definitely in place, neither layer being much more than 30 cm in thickness, and separated by a covered interval of about 60 cm that probably represents a weathered shale. The upper limestone bench is an ash-like, light buff, impure, porous micrite with few fossils visible to the naked eye. The lower limestone layer consists of dense, light gray to buff and tan packed phylloid algal biomicrite (Fig. 1). Most of the algal leaves are complete or at least consist of large pieces, although not in growth positions. Elsewhere, the Lonsdale Limestone consists largely of phylloid algae (Merrill, 1975:20-27), but those algae show a greater degree of fragmentation and the rock is more vuggy. The algal limestone at geologic section 12 does not lithologically resemble any other unit seen in the region.

Lithofacies and biofacies in the known Cramer localities are diverse. The type section has two prominent limestone ledges, plus some nodular limestones, and these are brachiopodal and mixed fragmental (''bioclastic''). At another sampled locality (Wanless' 1958 locality 169; Merrill, 1975, locality 2) there are several impure nodular brachiopodal limestones. Conodont faunas from the type Cramer are a normal, offshore, Missourian-age fauna, but those from the more impure limestones and shales at locality 2 represent a restricted, nearshore, probably brackish assemblage, the *Cavusgnathus*-biofacies (Merrill, 1975). These strongly contrasting localities are a mere 3 km apart.

The significance of the new locality is that it represents lithofacies totally unlike any previously reported for the Cramer. It is 12 km from the type section and 10 km from locality 169/2. Indeed, the uncertain stratigraphic correlation and distinctive, heretofore unknown lithology suggest the possibility that this body of rock may not represent a contigous extension of the unit named the Cramer, but may be a separate stratigraphic unit.

The biota is not especially helpful at resolving the correlation difficulties. Conodonts are extremely rare (frequencies of 0.9 per kg and 3.0 per kg for the upper and lower benches, respectively). The most common platform elements are assignable to *Streptognathodus cancellosus*, followed by *S. oppletus, S. elegantulus* and *Idiognathodus delicatus* in that order. Occurrences and relative abundances such as these are most compatible with an early Missourian age, although each of the taxa does occur in late Demoinesian rocks as well. Thus, an early Missourian age is most probable

for these rocks as would be expected, but positive correlation with the type Cramer cannot be established. The sparse conodont fauna indicates normal, unrestricted marine conditions. Associated with the conodonts are a reasonable number of distinctive, highly ornamented, siliceous sponge spicules.

If this occurrence does represent Cramer Limestone as seems probable, it is not only a new locality in a new area, but a completely new set of rock types as well.

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FIGURE 1 — Polished slab of a specimen from the lower limestone layer above Wanless' geologic section 12. Orientation is probably correct and scale bar is one centimeter.

NOTES ON SOME ILLINOIS PLANTS

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ABSTRACT: Four floral forms of some common vascular plants are reported for Illinois. Also included are range extensions of *Eleocharis parvula* (Roem. & Schultes) Link. and *Euonymus alatus* (Thunb.) Sieb. in Illinois.

Extensive field work during the past few years has resulted in the addition of some taxonomic forms to the Illinois flora as well as range extensions for *Eleocharis parvula* and *Euonymus alatus.* These taxa with the collecting data are listed below. Specimens are deposited in the Stover Herbrium of Eastern Illinois University (EIU).

Liatris pycnostachya Michx. *f. hubrichtii* Anders. This form with white corollas is listed for 5 counties in Missouri (Steyermark, 1963). A single specimen was found in a large population of the typical form.

Jasper Co.: Upland field at the Smallwood Township Park 1 mile NW of Bogota, Ill. (Sect. 30 T6N R9E), 1 Sept. 1978. A picture of this plant is deposited in the Stover Herbarium (EIU).

Mertensia virginica (L.) Pers. *f. rosea* Steyerm. This pink-flowered form is known from one location in Missouri (Steyermark, 1963). It has been observed in one location in Illinois where two clumps were found in a large population of the blue-flowered form.

Calhoun Co.: Open tallus slope about 1 mile south of Hardin, Ill. (Sect. 3 T11S R2W), 19 April 1978, J. Ebinger and R. Nyboer 17046 (EIU).

Mertensia virginica (L.) Pers. *f. berdi* Moldenke. This white-flowered form is listed for one county in Missouri by Steyermark (1963). It has been observed in the following locations in Illinois. At these sites are extensive populations of the common blue-flowered form and a small number of light blue-flowered individuals that may represent crosses between *f. virginica* and *f. berdi.*

Coles Co.: Mature terrace forest along Riley Creek about 2 miles west of Charleston, Ill. (Sect. 7 T12N R9E), 5 May 1978, J. Ebinger 17061 (EIU). Three clumps of the white-flowered form were observed.

Calhoun Co.: Open tallus slope about 1 mile south of Hardin, Ill. (Sect. 3 T11S R2W), 19 April 1978, J. Ebinger and R. Nyboer 17045 (EIU). Eleven clumps of the white-flowered form were observed.

Jersey Co.: Wooded tallus slope about 3 miles south of Nutwood, Ill. (Sect. 21 T7N R13W), 21 April 1979, J. Ebinger 17582 (EIU).

Prunella vulgaris L. var. *lanceolata* (Bart.) Fern *f. candida Fern.* This form is listed for one county in Missouri (Steyermark, 1963) and was recently found at the following locality in southern Illinois.

Johnson Co.: Upland open field near railroad tracks just west of the Herron Pond-Wildcat Bluff Nature Preserve about 2 miles north of Belknap, Ill. (Sect. 30 T13S R3E), 10 Oct. 1978, J. Ebinger and R. Fried 17480(EIU).

Eleocharis parvula (Roem. & Schultes) Link. This wide ranging species was first reported for Illinois by Ebinger and Nyboer (1976). Since that time two additional populations have been found in eastern Illinois.

Coles Co.: On mudflat of small pond 2 miles SW of Charleston, Ill. (Sect. 28 T12N R9E), 7 Sept. 1976, J. Ebinger 16161 (EIU).

Effingham Co.: On mudflat at Lake Sara about 5 miles west of Effingham, Ill. (Sect. 17 T8N R5E), 26 Sept. 1978, J. Ebinger 17454 (EIU).

Euonymus alatus (Thunb.) Sieb. This species was first reported as an adventive in Illinois by Ebinger and Phillippe (1973). Recently Swink (1974) reported it for DuPage Co. while Mohlenbrock and Ladd (1978) listed it for six counties in Illinois. It appears that this species is spreading from cultivation and that it is able to survive and reproduce.

Coles Co.: Shrub 2 m tall in terrace forest at Fox Ridge State Park (Sect. 13 T11N R9E), 8 Oct. 1974, J. Ebinger 15216 (EIU). More than 200 individuals were obseved in the area.

Coles Co.: Shrub 2 m tall near path in upland woods at Lakeview Park 1 mile SE of Charleston, Ill. (Sect. 24 T12N R9E), 13 Sept. 1978, J. Ebinger 17417 (EIU).

Lake Co.: Shrub 1½ m tall in Kranes Woods about 3 miles south of Antioch, Ill. (Sect. 36 T46N R9E), 9 Aug. 1976. J. Ebinger 16033 (EIU).

Will Co.: Shrub at edge of trail in campus woods of Joliet Junior College (Sect. 22 T35N R9E), 28 June 1976, D. Knapp 13 (EIU).

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EDITOR'S NOTE

With this issue of **Transactions**, we begin a new look in the publication. A modernization of the style, a more contemporary image and, hopefully, a more streamlined format marks this departure. The sciences keep pace with, or lead society to a great extent, and the publications and their medium must also reflect contemporaneity.

We hope soon to be on a regular and timely basis with the publication and we reiterate our call for quality submissions to this journal. Through the calibre of the papers appearing in this quarterly, the Illinois State Academy of Science will have its image reflected.

Basil C. Hedrick
Editor

The design on the cover of this issue and the ones to appear on future issues are adapted and transformed from material originally published in **Kunstformen der Natur** by Ernst Haeckel in 1904. His observations of natural forms prior to the electron microscope are remarkably exact, but have been reversed, combined and altered for use on the cover. You are welcome to unravel the mystery (some are easy, others almost impossible), but the Editor and the designer will not enter in to correspondence concerning these symbols of nature's endless formal variation.

Cover design by Bob Evans

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SAMPLE SIZE AND PALYNOLOGY: A MIDWESTERN TEST

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ABSTRACT

The reliability of palynological data is a direct result of the number of grains counted per sample. This amount must be large enough so that the data accurately reflect the ratio of all pollen grains in the original sample. Published pollen counts have varied widely but the 200 grain count has been commonly adapted. Based on the analysis of six different ecological situations in the lower Illinois River Valley of western Illinois we find that in terms of reliability of percentages of individual pollen types and the number of new types added with additional counting, 400 grain counts are necessary for good ecological and climatic interpretations in the forested midwestern United States.

A basic premise of paleoenvironmental reconstructions based on the analysis of fossil pollen is that the annual complement of atmospheric pollen reflects the local and regional vegetation which produced it. This relationship between vegetation and what has frequently been called the pollen rain has been amply demonstrated by practically every researcher in Quaternary palynology since Von Post. Changes in pollen frequency are thus interpreted as reflecting changes in the vegetation and ultimately changes in climate.

The recovery, analysis and interpretation of pollen records are the basic ingredients of palynology and one of the first of many decisions confronted by the investigator during data collection is the choice of sample size (N): the number of pollen grains to be counted per sample. This basically simple statistic is crucial if the results of any analysis are to be significant.

Although there are several excellent discussions of the pollen sum, i.e., those taxa forming the base for the calculation of pollen percentages (Faegri and Iverson 1975: Wright and Patten 1963), the matter of total sample size is rarely mentioned. Fortunately, the majority of published pollen diagrams have been based on sufficiently large counts to avoid most obvious problems. However, there are many examples in which interpretations have been based on quite small numbers of pollen grains, and these can easily lead to erroneous conclusions.

A perusal of the literature indicates that there are at least three basic strategies for counting pollen: 1) counting all pollen types encountered within a specific area of the slide; 2) counting until a fixed number of marker species, such as arboreal pollen, are identified; and 3) counting all pollen types until a predetermined fixed sum is reached. Combinations of these methods are frequently found as well as such practices as counting pollen for a set time period and counting to any amount over a set minimum.

Each of these strategies has advantages and disadvantages, and any method chosen involves a trade-off in terms of reliability of the data versus the amount of time expended. It is an unfortunate fact, but pollen analysis is extremely labor intensive.

Counts of a specific area of a slide or counts based on a fixed number of marker grains usually result in wide variations in N. Such results, although they are often compared, may not be statistically

equivalent for two reasons. First, the number of taxa encountered is directly dependent on N and second, the larger the N the closer the pollen count ratios will be to the actual ratios in the population. For this discussion, the population is all of the pollen grains in the sample.

As a result of the lack of uniformity, published samples sizes have ranged from less than 25 to more than 1000 grains. Martin's data from southern Arizona (1963:31) indicated that an N of 200 grains was adequate for pollen studies in the Sonoran Desert.

Since this is one of the few published studies addressing the problem of N in pollen analysis, the 200 grain pollen count has been widely applied to pollen studies from other parts of the country. It is the purpose of the present paper to provide evidence on the minimum sample size which will provide good species representation and reliability of percentages for pollen samples from the forested regions of the midwestern United States.

METHODS

The annual pollen accumulation at any given locality is frequently refered to as the pollen rain, and moss polsters provide an easy and convenient method for its sampling (Carroll, 1943). Although often inconspicuous, moss polsters occur commonly in environments ranging from mesic prairie to dense forest. As they grow they incorporate the pollen that settles on them into their expanding mass, and their slightly acidic internal environment is beneficial in preserving pollen. As a result, the pollen trapped within a polster will have accumulated over several years and will reflect an average of the regional pollen rain over that period.

For this study, moss polsters were collected from six sites in the lower Illinois River valley of western Illinois. These sites were located in a number of environmentals including upland forest, both east- and west-facing talus slope forests, sand ridge forest, floodplain forest, and floodplain prairie. All of the areas have been disturbed to some extent by man's recent activities. The polsters were collected during the winter at the time of minimal atmospheric pollen concentration so that the last full pollination season would be represented; the polsters averages 5-10 cm in diameter. They were removed from their substrate in the field, sealed in plastic bags, and frozen until processed.

The polster samples were processed following standard palynological procedures (Faegri and Ivensen, 1975). The entire polster was first boiled in 10% potassium hydroxide to disperse the individual moss plants and to suspend the pollen. This suspended material was screened from the moss, treated with hydrochloric acid to remove the carbonates, hydrofluoric acid to remove the silicates, and then acetolyzed to remove excess organic matter. The residue was treated briefly with 5% potassium hydroxide, rinsed until clean and placed in glass vials with glycerine. A drop of residue was stained with basic fuchsin, spread thinly and as uniformly as possible on a pre-cleaned glass slide, and covered with a 22 x 22 mm glass cover slip. The edges of the cover slips were sealed with lacquer to prevent evaporation and accidental movement. A total of 1000 pollen grains were counted from each sample and each 1000 grain count consisted of 20 sequential 50 grain counts so that sample size could be measured against species appearance and number.

RESULTS AND DISCUSSION

The number of pollen types encountered in any pollen count is a direct function of the size of N and of the relative abundance of the pollen types to each other. The rate of appearance of new types increases rapidly with increases in a low N, then approaches zero as N reaches higher values. One objective of this study was to examine the relationship between increases in N and the appearance of new pollen types. This is of primary importance when making ecological interpretations from pollen data.

As shown in Figure 1, the greatest increase in new types occurs between 0 and 100 grains. Averaging the six sites, 15.5 types were encountered in the first 100 grain count. With increases in N, the rate of increase in new types declines: 5.1 additional types between 100 and 200 grains, 2.4 between 200 and 300 grains, and 2.3 between 300 and 400 grains, 2.0 between 400 and 500 grains, and 2.8 additional types added by increasing the sample size from 500 to 1000 grains. Between 200 and 400 grains, the rate of appearance of new types declines to 2.3 per 100 grains. Between 400 and 1000, the rate declines to 0.8 new types per 100 grains. It is notable that although there are differences between environments, as illustrated in Figure 1, the rate of increase is nearly identical for all environments and vegetation types in the Lower Illinois Valley.

The first appearance of a given pollen type in any count is a function of its abundance in the population, (i.e., the pollen grains being counted). Since percentages must always total 100%, the more pollen types that occur in a population the smaller their individual percentages will be. To compensate for this constraint, larger counts must be made to guarantee inclusion of types with low rates of occurrence in the population.

Based on the normal approximation to the binomial distribution (Orkin and Drogin 1975:81) the minimum sample size can be computed that is necessary to insure inclusion of at least one individual of a pollen type constituting a given percent of the population. Pollen types which are ► 7% of the population will have a 99% probability of appearing at or before 100 grains are counted, types which are ► 4% of the population will appear at or before 200 grains are counted, and types which are ► 2% of the population will appear at or before 400 grains. To be 99% certain of including pollen types comprising 1% of the population, 725 grains must be counted.

Pollen counts are usually composed of a few dominant and many minor types. In the case of the sites discussed here, 4 types account for 95% of the pollen at three of them and 5, 3, or 2 at each of the other sites; the average is 3.6 types. Although the minor and trace forms may contain significant information, it is to a large extent the two or three dominant species that reveal the overall nature of the vegetation. The basic problem for the investigator then is, at what values of N does the percentage variation for the dominant pollen types cease being significant? Plotting the range of confidence limits for percentages against increasing pollen sums (Fig. 2) demonstrates that as sample size increases, the range of probable variation decreases. Values differing by as much as 10% can only be separated statistically at the 95% confidence level in a sample size of greater than 350. Taking this into consideration, Maher (1972) suggested that confidence limits should be included with all percent values in pollen diagrams. With a fixed N, on the other hand, corresponding percentage values fall within the same confidence limits and thus are directly comparable. In addition, uniform sample size is necessary if the pollen data is to be subjected to certain types of statistical analyses.

The degree to which the calculated percentage for a pollen type approaches its actual occurrence in the population is also a function of N. The larger the N, the more closely the pollen types in the count will approximate their ratio in the population. To determine at what value of N, the percentage of various types would cease fluctuating and stabilize, the percentages of selected types from two sites were plotted against increasing N (Fig. 3). The results show that between 50 and 300 grains the percentages of individual types fluctuate widely but that they become relatively stable between 300 and 400 grains. Beyond 400 grains, all types show values within $\pm$1 1/2% of their value at 1000 grains.

For these Illinois samples, both the rate of appearance of new pollen types and the percentage fluctuation of individual pollen taxa decrease markedly by 400 grains. Increasing the count to 1000 grains yielded, on the average, less than one new type. In the desert southwest, Martin (1963) found 19 types in 1000 grains while in Illinois we found between 25 to 33 types with the same N. The larger number of types in samples from the forested Midwest requires an N larger than the 200 grains determined acceptable for Arizona. As discussed earlier, when more types are present in the pollen rain, or the pollen rain is not heavily dominated by a few types, a larger pollen count (N) is needed.

The sample size of any pollen count reflects a balance between the amount of time expended counting and the reliability of the data. In terms of both the individual percentages of pollen types and the number of new types added with additional counting, approximately 400 grains provides a stable statistical basis for evaluating differences and interpretating pollen data. The small improvement that results with N larger than 400 does not appear, at least in this example, to offset the additional counting time.

ACKNOWLEDGMENTS

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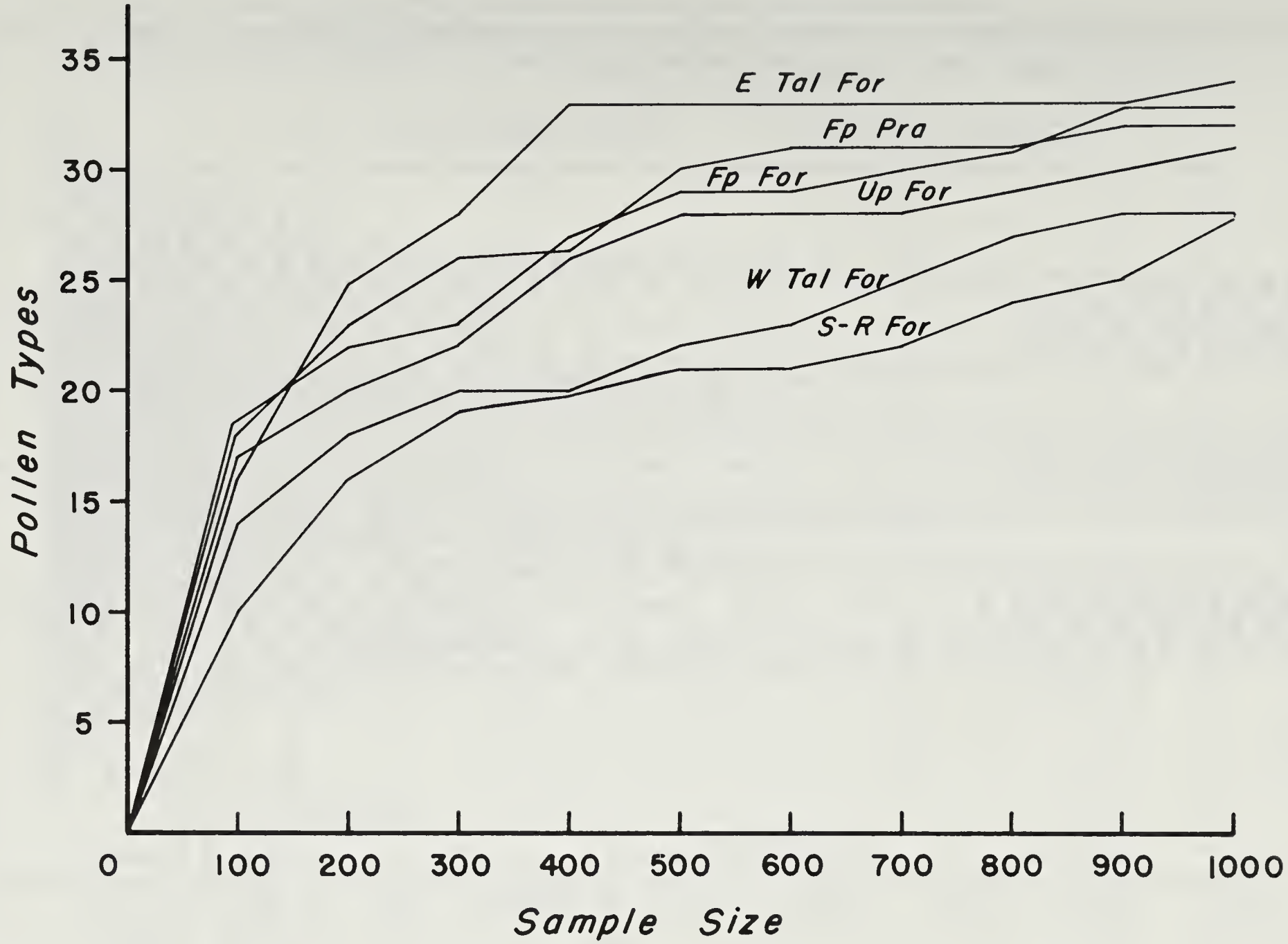
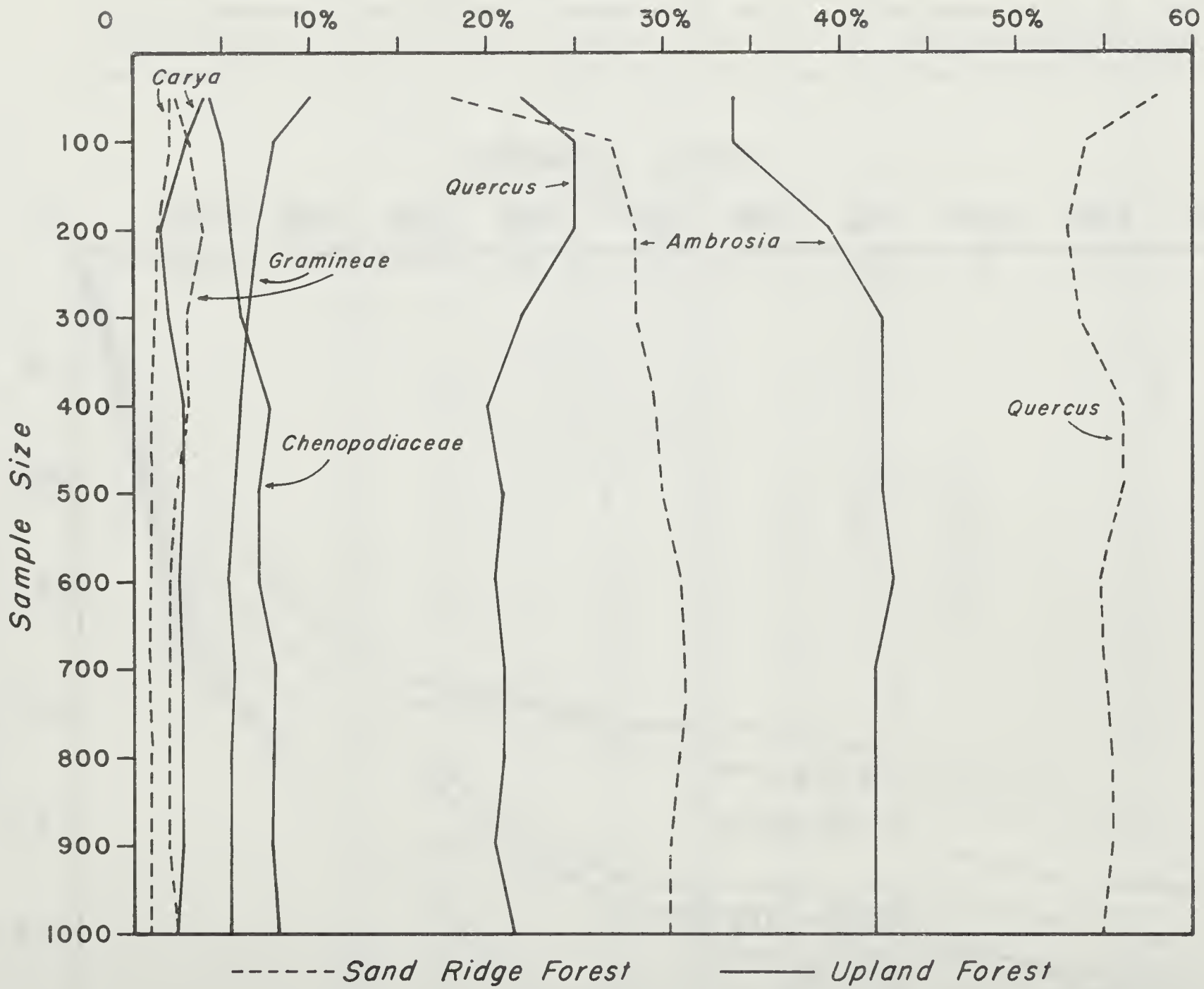
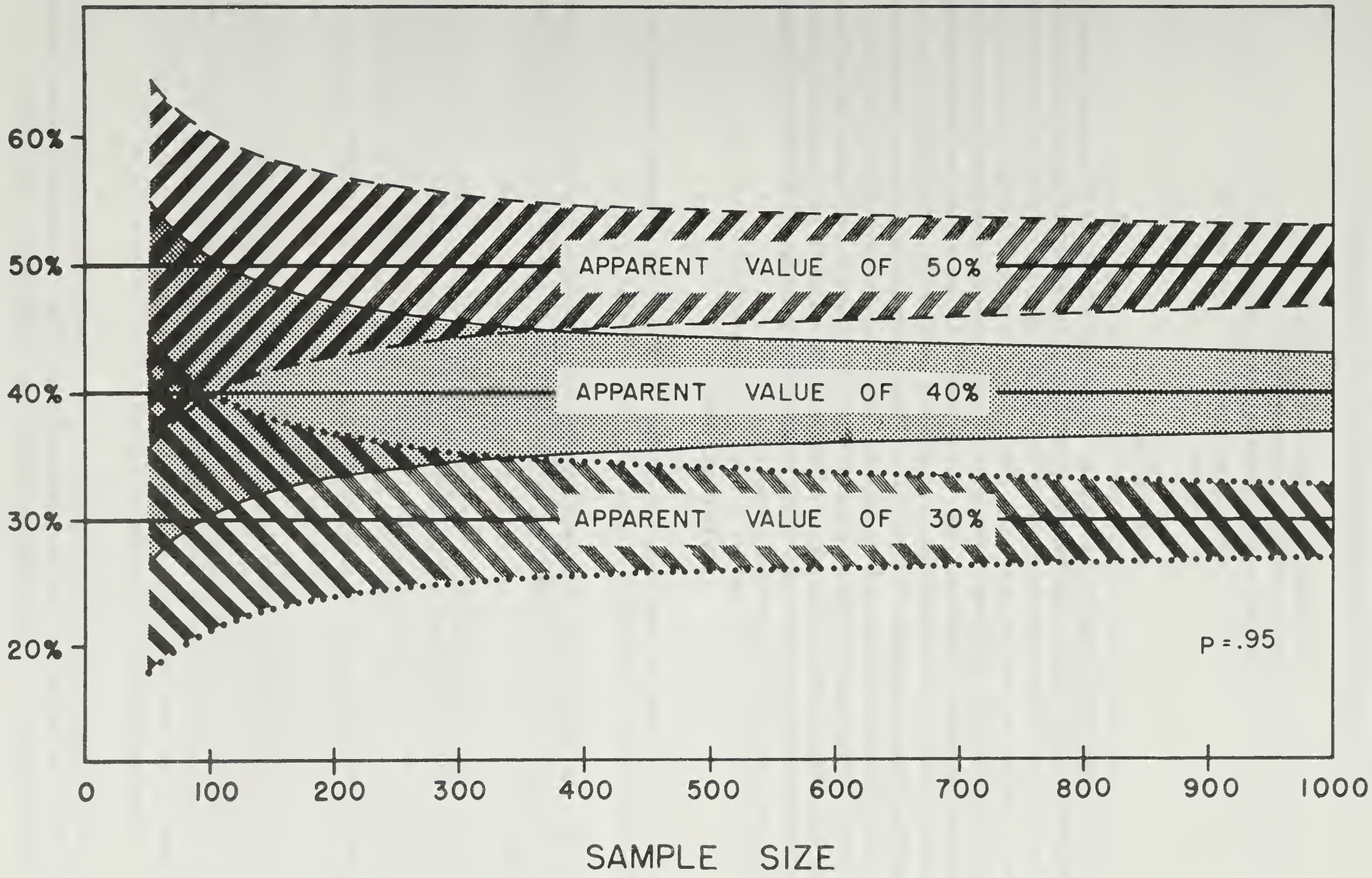


1. The number of pollen types encountered as a function of increasing sample size for six environments in the lower Illinois River Valley of western Illinois; E Tal For - east facing talus slope forest, Fp Pra - floodplain prairie, Fp For - floodplain forest, Up For - upland forest, W Tal For - west facing talus slope forest, S-R For - sand ridge forest.



2. The distribution of binomial confidence limits adapted from (Rohlf and Sokol, 1969) for values of 30%, 40%, and 50% (p=0.95) with increasing sample size. A sample of at least 350 grains is necessary to differentiate between values even as large as 10% at this confidence level.



3. The percentages of selected pollen types as a function of sample size for two forest environments, sand ridge forest and upland forest.

EFFECTS OF CAFFEIC AND CHLOROGENIC ACIDS ON RADIAL GROWTH, ACERVULUS PRODUCTION, AND SPORULATION OF *COLLETOTRICHUM DEMATIUM* VAR *CIRCINANS*

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ABSTRACT

Spores of Colletotrichum dematium *var* circinans *(Birk.) v.Arx were point inoculated onto V-8 juice agar buffered over a range of approximately pH 3 to approximately pH 8. Spores were also inoculated onto plates of V-8 containing caffeic or chlorogenic acids, two phenols, at concentrations of 10^{-3} M to 10^{-8} M over the same pH range. Effects on radial growth, acervulus production, and sporulation were measured. Major effects on radial growth and acervulus production were due to pH. Concentration of phenols modified results. Best radial growth, on media without phenols, occurred at pH 5.9. When phenols, in all concentrations, were added to buffered V-8 radial growth was improved at lowest pH for all concentrations of caffeic and chlorogenic acids and at highest pH values at concentrations of 10^{-3} M for caffeic and all concentrations of chlorogenic acid. Most acervuli were produced on media, without phenols, at pH levels of 4.1 and 5.1. Best acervulus production, on media with phenols, occurred at all concentrations of both phenols on media with pH values of 3.1 and 4.1. There was poor correlation between radial growth and acervulus production (r^2=0.26). Sporulation was inhibited on media of pH 3.1, with and without phenols.*

INTRODUCTION

Walker *et al.* (1929) reported what they considered to be the first case of disease resistance due to presence of a chemical entity, specifically protocatechuic acid, a phenol.

In years to follow several authors have described effects of phenolics on pathogenic fungi. Several reviews on the subject have been published (Pridham 1960, Wood, 1967, Kosuge 1969, Schonbeck and Schlosser 1976).

Beginning in 1953 characterizations of phytoalexins were published (Uritani 1953, Kuc *et al.* 1956, Keen *et al.* 1971). These chemicals are generally thought to be formed de novo in response to infection (Cruickshank *et al.* 1971, Kuc 1976). However, trace quantities of these compounds have been found in healthy tissue (Kuc 1976). This has led to the suggestion that speed and magnitude of accumulation of phytoalexins is more important than simple presence of these compounds (Keen 1971, Keen *et al.* 1971).

That phenols and phytoalexins contribute to disease resistance in plants has come to be accepted. Walker and Stahmann (1955) determined that in onion catechuic and protocatechuic acids are the chemicals responsible for protection. Somasekhara (1974) found that exposure of onion bulb scales to ambient air induced an increase in caffeic acid and the appearance of chlorogenic acid. Caffeic acid was found to stimulate germination of *Botrytis allii* spores while high concentrations of chlorogenic acid inhibited germination at pH values of 4, 5, and 6.

Caffeic and chlorogenic acids are nonspecific inhibitors of many enzymes, and they polymerize to lignin-like compounds resistant to microbial degredation (Kuc 1976). These acids have been found in healthy and infected Irish and sweet potatoes (Johnson and Schaal 1955, Uritani 1963, Sato *et al.*

1971) and in carrot (Condon 1962). Their function, either as preformed phenolics or de novo formed phytoalexins, has not been determined. Kuc (1976) reported that quinones of these compounds are toxic to plant cells and may explain the hypersensitive reaction associated with some infection processes.

The purpose of this project was to determine the effects caffeic and chlorogenic acids had on radial growth, acervulus production, and sporulation of *Colletotrichum dematium* var *circinans* (Berk.) v.Arx, the onion smudge pathogen.

MATERIALS AND METHODS

Caffeic acid (4-dihydroxycinnamic acid) and chlorogenic acid (3-caffeoyl guinic acid) were added to sterile V-8 juice agar (V-8), adjusted to pH values of approximately 3 to 8. Final concentrations of acids in media were 10^{-3} M to 10^{-8} M. Controls consisted of pH adjusted V-8 without caffeic and chlorogenic acids. Addition of acids did not significantly change pH of media.

Using sterile techniques a small amount of spores, from month old colonies of *C. dematium* var *circinans*, were point inoculated to the approximate center of plates. Cultures were incubated under cool-white fluorescent light (Sylvania®, 350-750 nm, 1,133 lux) for ten days at which time average radial growth, along two axes of each of 3 plates for controls and treatments, were measured. A total of 126 cultures comprised the study. In addition numbers of acervuli were counted. Three radii were randomly selected. On each radius a 1 cm long line was placed half-way in from colony edge, and acervuli along that line counted. Means for radial growth and numbers of acervuli formed were compared statistically using analysis of variance and Student-Newman-Kuell's post hoc test ($p=.05$).

Cultures were observed daily for sporulation, defined as masses of spores visible to the eye.

RESULTS AND DISCUSSION

Effects on radial growth and acervulus development of *C. dematium* var *circinans*, established on buffered media or buffered media with added phenols, were due primarily to media pH. Best radial growth occurred on media, without phenols, with an initial pH of 5.9. Results were modified, in some cases, by phenols. There was no inhibition of radial growth with addition of phenols. Caffeic and chlorogenic acids, in all concentrations, allowed for significantly improved radial growth at lowest pH, and at higher pH, values · at concentrations of 10^{-3} M for caffeic acid. For most conditions results were not significantly different and could be grouped for comparison to controls (Table 1).

Significantly more acervuli were produced on control media of pH values 4.1 and 5.1, than on all other control media. Addition of phenols stimulated production of significantly more acervuli on media of initial pH of 3.1 and 4.1. Results for various concentrations of phenols were grouped for comparison to controls (Table 2). It is believed that this is the first report that numbers of acervuli produced by a fungus can be affected by concentrations of phenols. There was poor correlation ($r^2=0.26$) between numbers of acervuli/cm formed on 10 day old cultures and radial growth for those cultures.

Sporulation occurred after 3 days on most media. However, sporulation was inhibited by 48-60 hrs on media of lowest pH with and without phenols. It is know that *C. lindemuthianum* is capable of raising media pH (Leach 1923). It is believed that this is also the case here, with 48-60 hrs being the time period required to adjust media pH to a level conduscive to sporulation.

Akazawa and Wada (1961) indicated that oxidation or degredation products of chlorogenic acid can be detrimental to fungal growth. In potato, quinones of caffeic and chlorogenic acids have been implicated in disease resistance (Metlitskii and Ozeretskovskaya 1958, Kuc 1972). Others have documented what appears to be an alternative role for caffeic and chlorogenic acids in host-parasite interactions. Lee and LeTourneau (1958) stated that chlorogenic acid may lower cell pH to a level below the range that will support growth of the fungus. They also indicated that chlorogenic acid may be a possible carbon source for *Verticillium albo-atrum*.

Data presented here indicates that caffeic and chlorogenic acids are not toxic to *C. dematium* var *circinans* in culture and may, at some concentrations and pH values, support radial growth and acervulus production.

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Table 1. Radial growth of Colletotrichum dematium var circinans on V-8 juice media, at various pH levels, with and without caffeic and chlorogenic acids. Means represent measurements on 126 cultures 1/

	Radial Growth (cm)					
	pH					
Treatment	3.1	4.1	5.1	5.9	6.9	8.1
Control (no phenols)	1.05 a *2/	3.43 a ***	3.47 a ***	3.65 a ****	3.17 a **	3.08 a **
Caffeic acid (10^{-3}M)	2.24 b *	3.30 a **	3.40 a **	3.62 a ***	3.87 c ***	3.78 b ***
Caffeic acid (combined 10^{-3}M -10^{-8}M)	2.24 b *	3.30 a **	3.40 a **	3.62 a ***	3.41 a **	3.27 a **
Chlorogenic acid (combined 10^{-3}M -10^{-8}M)	2.12 b *	3.44 a **	3.44 a **	3.73 a ****	3.60 b ***	3.58 b ***

1/ 6 pH levels x 7 Molar levels x 3 cultures/Molar level

2/ Means in a column followed by the same letter are not significantly different at the 5% level (SNK); means in a row followed by the same numbers of astericks (*) are not significantly different at the 5% level (SNK)

Table 2. Numbers of acervuli/cm produced by Colletotrichum dematium var circinans on V-8 juice media at various pH levels, with and without caffeic and chlorogenic acids. Means represent 378 measurements1/

	Numbers of Acervuli/cm					
	pH					
Treatment	3.1	4.1	5.1	5.9	6.9	8.1
Control (no phenols)	12 a *2/	26 a **	30 a **	18 b *	19 a *	16 a *
Caffeic acid (combined 10^{-3}M - 10^{-8}M)	34 b ***	32 ab ***	29 a **	23 a **	23 a **	18 a *
Chlorogenic acid (combined 10^{-3} M - 10^{-8} M)	34 b ***	35 b ***	29 a **	20 ab *	22 a **	17 a *

1/ 6 pH levels x 7 Molar levels x 3 cultures/Molar level x 3 measurements/culture

2/ Means in a column followed by the same letter are not significantly different at the 5% level (SNK); means in a row followed by the same number of astericks (*) are not significantly different at the 5% level (SNK)

ISOLATION OF *PHOMOPSIS CONORUM* AND *SORDARIA FIMICOLA* FROM *PINUS SYLVESTRIS* IN SOUTHERN ILLINOIS

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Two fungi, Phomopsis conorum *and* Sordaria fimicola*, were isolated from apparently cold weather stressed Scotch (Scots) pine (*Pinus sylvestris*). It is believed this is the first report of these fungi from* P. sylvestris *in Illinois. Both appear to be saprobic on* P. sylvestris.

In Illinois, Scotch (Scots) pine (*Pinus sylvestris* L.) is extensively planted as a Christmas tree crop. One of the strains used, the Spanish, is particularly susceptible to the physiological disease of winter burn (Dirr 1977). The disease is manifest as browning of the needles due to excessive winter transpiration. Under these conditions moisture lost exceeds the supply of liquid water in the plant causing stress. The water is not replenished since it is bound in a frozen state in the soil (Smith 1970).

During May, 1978, samples of *p. sylvestris* (Spanish strain), exhibiting possible symptoms of winter burn, were submitted to the Illinois Department of Agriculture for testing to determine if fungal infection could be responsible for the observed symptoms. The trees were growing near Pinckneyville, Perry County, in a mixed stand with other pine species which did not exhibit the symptoms. The condition of the effected trees was observed through the remainder of the year. Diseased trees improved, *i.e.* exhibited near normal needle coloration, and were sold during December, 1978. The syndrome is apparently recurring following the harsh winter of 1978-1979 in Illinois.

Portions of twigs and needles were processed using standard methods (Tuitte 1969). Sections were placed on V-8 juice, potato-dextrose, and malt extract media for incubation. All media contained 2% agar. Cultures were maintained in dark or continuous light (Sylvania®, cool-white fluorescent, 300-750 nm, 1,133 lux) at 24 + 1 C for 10 days after which time they were observed for sporulation and subsequent identification. All cultures produced spores in light and dark.

At least one species each in the genera *Alternaria, Penicillium,* and *Cephalosporium* (fungi considered to be saprobic on *P. sylvestris*) were identified from samples. Two other fungi were consistently isolated. There were *Phomopsis conorum* (Sacc.) Died. (ATCC 38600) and *Sordaria fimicola* (Rob.) Ces & DeNot. (ATCC 36982). Of the two, only *P. conorum* has been reported in association with this pine. That report was from Iowa (Gilman and McNew 1940), and the association was considered to be saprobic. This report extends the range of *P. conorum* on *P. sylvestris,* from Iowa to southern Illinois, and, to the best of our knowledge, records the presence of *S. fimicola* for the first time on this pine species.

Although *P. conorum* has been recovered from pine, and the genus is often isolated from diseased trees of other species (Hahn 1930, Gilman and McNew 1940), it is not considered to be a pathogen of *P. sylvestris* (USDA Index of Plant Diseases 1970, Hepting 1971). The normal substrate of *S. fimicola* consists of decaying organic matter, seed, or soil (Cain 1934, Cain and Groves 1948, von Arx 1970).

Because the trees recovered and the symptoms suggested a physiological, rather than a microbially induced condition, it is concluded that the fungi are saprobes on *P. sylvestris*.

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[1] At the time the project was under taken the senior author was Plant Pathologist, Illinois Department of Agriculture, Bureau of Plant and Apiary Protection, Springfield, IL 62706.

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A HISTORY OF ILLINOIS BRYOLOGY

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ABSTRACT

A brief history of the development of bryology in North America is followed by a chronological account of the study of our state bryoflora. This is appended with biographical sketches of those persons instrumental in generating our present knowledge of this group of plants in Illinois.

INTRODUCTION

Although Gotthilf Henrich Ernst Muhlenberg (1753-1815) has been heralded by many as the father of American botany, he, as other early North American plant systematists, submitted bryophyte collections to various European scholars for determination. Not until 1821 was there an attempt to enumerate and describe the Musci and Hepaticae of the United States when Lewis David von Schweinitz (1780-1834) published his *"Specimen Florae Americane Septentrionalis Cryptogamicae . . . ."* Schweinitz had his university training in Germany where he became familiarized not only with the structure of the lower cryptogams but the literature as well. His treatise laid the groundwork for future bryological endeavors in America, providing native botanists with the materials for accurate determination of bryophytes, access to properly named specimens for comparison and usable descriptions of North American plants. Such outstanding American botanists as John Torrey (1796-1873) and his protege Asa Gray (1810-1888) developed substantial interests in bryophytes, influenced largely by Schweinitz's efforts. Their involvement with the cryptogams always remained overshadowed by the intrigue of the vascular flora, though. In the late 1830's correspondence with Torrey and later with Gray was initiated by William Sullivant (1803-1873), who had developed an interest in botany and was determined to know all the plants in his locale of central Ohio. His interest in bryophytes particularly was nurtured by Torrey and Gray and culminated in his preparation of the final 56 pages of Gray's renowned *"Manual of Botany"* in 1848. This section was comprised of Musci and Hepaticae complete with accurate, original, detailed illustrations. At once Gray's *"Manual"* became the standard work for all American botanists. Through Sullivant's efforts the bryophytes were not only nicely figured but for the first time were described in English; this permitted even the amateur now to collect and identify these small plants. An upsurge of interest was kindled which soon resulted in the inclusion of bryophytes in numerous regional and state floras as well as check lists throughout the central and northeastern United States.

ILLINOIS BRYOLOGY

In 1857, Increase Lapham (1811-1875) published the first major account of the Illinois flora, which consisted of 59 pages of species followed by an additional 62 pages devoted solely to grasses. The expansion of this flora came quickly from Illinois botanists. The first of these was by Frederick Brendel in 1859. Brendel's paper included not only vascular plants but was appended with a checklist of *"Mosses occurring around Peoria"* and thus for the first time Illinois species of Musci were enumerated. Concomitantly, George Vasey read his research paper entitled *"Mosses of Illinois"* before the State Natural History Society at Bloomington in June, 1859, a paper which was therewith published by the society. The detailed account of bryophytes in Gray's *"Manual"* was doubtless instrumental in the genesis of these early reports. Some 15 years later, Harry Patterson listed 38 moss

species as the final page of his lengthy *"Plants in the vicinity of Oquawka Illinois"* (1874). Soon after followed a paper entitled, *"A list of the Mosses, Liverworts, and Lichens of Illinois,"* which included 165 species of mosses and 45 species of liverworts compiled from a lengthy period of Illinois botanizing by John Wolf and Elihu Hall (1878). As a result of this endeavor and their correspondence with William Sullivant and his assistant Leo Lesquereux (1806-1882), numerous Illinois specimens were later cited in the *"Manual of the Mosses of North America"* by Lesquereux and T.P. James (1803-1882) in 1884. Both of these Illinois bryologists were honored in that work by the inclusion of moss species under their namesakes: e.g., *"Weisia wolfii* sp. nov., Lesq. & James" from near Canton, Illinois and *"Conomitrium hallinum* Sull. & Lesq." (=*Fissidens hallianus* (Sull. & Lesq.) Mitt.) from decayed wood in wells, Illinois. In that same year, 1884, Lucien Marcus Underwood, a brief resident of Illinois, published his *"Descriptive Catalogue of the North American Hepaticae, North of Mexico"* in the Bulletin of the Illinois State Laboratory of Natural History. This likewise included the citations of numerous Illinois specimens with a separate appendix indicating the geographic distribution of American Hepaticae in which the Illinois species were marked with an asterisk. By the close of the 19th century, then, the Illinois bryophytes had been given consideration in all of the major North American bryophyte publications.

The early 1900's saw only limited additions to and amplifications of the state bryoflora with E.J. Hill of Chicago providing the major contributions. In the 1930's, however, Stella Hague renewed the study of our bryophytes with a series of papers and lectures on Illinois mosses and liverworts in association with the Illinois State Academy of Science. It was her influence that again stimulated various students to rekindle an all but dying interest in this neglected plant group in Illinois. Since Hague's last Illinois bryophyte publication in 1937, several additions to our bryophyte flora have been published, most being county or localized regional accounts.

Though the study of the Illinois bryoflora subsequent to the period of Wolf and Hall has been somewhat meagre, numerous persons have had particular interest in this plant group. Below follow sketches of those instrumental in generating our present knowledge of the occurrence of these plants in Illinois.

BIOGRAPHICAL SKETCHES

ARZENI, CHARLES BASEL (1925-). Doctoral student of W.C. Steere at the University of Michigan and botanist at Eastern Illinois University since 1965. He prepared a check list of bryophytes based on his collections from Coles and Clark Counties (1947) and more recently co-published on the bryophytes of Shelby County (1975). A recent note (1976) reported the addition of *Buxbaumia aphylla* to the Illinois flora.

AUSTIN, COE FINCH (1831-1880). Resident of New Jersey whose bryological interest was turned primarily to the Hepaticae through the encouragement of William S. Sullivant (vide: Rodgers, A.D. III, 1940). His correspondence with Elihu Hall and John Wolf resulted in the inclusion of Illinois specimens in his numerous publications. His *"Hepaticae Boreali-Americanae Exsiccatae"* was issued in 1873. Although no Illinois collections were specifically incorporated in this series, No. 133 *Grimaldia barbifrons (=Mannia fragrans)* included "also in Illinois, Hall" printed on the label. According to Underwood, a complete set of this *"Exsiccatae"* was later at his disposal in the State Natural History Laboratory in Bloomington. This has not since been located at either Illinois State University or at the Illinois State Museum in Springfield (vide: Fuller, 1955).
Bibliography: Britton, E.G. 1910. (portr.); Rodgers, A.D. 1940.

BARRICK, STELLA ARAMINTA (NEE HOLMES) (. . . - . . .). As a student of Stella Hague's at the University of Illinois during the early 1930's, she co-authored a 1933 report of mosses from Coles and Crawford Counties based on her collections; also collected and published with fellow student G.H. Boewe.

BOEWE, GIDEON H. (1895-1970). A master's student at the University of Illinois from 1928-1930. Although his main interest was in plant pathology, he collected moss specimens from the Apple River Canyon, Mississippi Palisades, and White Pines State Parks in 1934 with Stella Barrick. This account was published in 1935.
Bibliography: Evers, R.A. and J.C. Carter. 1971 (portr.).

BRENDEL, FREDERICK (1820-1912). Peoria physician, botanist and meteorologist. He published a list of 27 mosses in the vicinity of Peoria in 1859 which was then expanded to 78 moss species and 24 liverworts in his *"Flora Peoriana"* in 1882 (the English version did not appear until 1887). His account was prefaced with: "Descriptions of genera and species are unnecessary, in such treatise, as those can be found in Gray's Manual, which, being in every botanist's hand, offers sufficient means to identify all the species found in our country."
Bibliography: Chase, V.H. 1931. (portr.).

CALKINS, WILLIAM WIRT (1842-1914). A Chicagoan, amateur lichenologist and bryologist and friend of E.J. Hill; in 1910 he published an annotated list of 51 moss species collected by him from within a radius of about 20 miles from Chicago, within the boundaries of Cook County.

CRANDALL-STOTLER, BARBARA J. (1942-). Doctoral student of Margaret Fulford's at the University of Cincinnati and botanist at Southern Illinois University since 1969, she has worked primarily on the development and physiology of bryophytes. She recently co-published a floristic account of liverworts from Lusk Creek (1979).

DOYLE, W.T. (1929-). Doctoral student of J.M. Proskauer's at the University of California-Berkeley and botanist at the University of California-Santa Cruz, he was an instructor at Northwestern University in 1960-61 and co-authored a paper on the succession of bryophytes in an Illinois bog (1965).

DREXLER, ROBERT VIRGIL (1910- . . .). A student of Stella Hague's at the University of Illinois in the 1930's; co-authored a list of liverworts collected by himself and Hague from a variety of counties from throughout Illinois (1938).

FRYE, THEODORE CHRISTIAN (1869-1962). Born in Washington, Illinois, he was educated at the University of Illinois with graduate studies at the University of Chicago under the tutelage of John Coulter (1851-1928). He took his Ph.D. in 1902 and then accepted a position at the University of Washington. There he developed his interest in the bryophytes and published the comprehensive *"Hepaticae of North America"* (1937-1947) with a former student, Lois Clark. Countless species are listed as being from Illinois, although these reports are based on earlier published accounts rather than on an actual examination of extant specimens.
Necrology: Howard, G.E. 1963. (portr.)

GALLIGAR, GLADYS CHARLOTTE (1904- . . .). A student of Stella Hague's at the University of Illinois in the 1930's, she prepared a check list of bryophytes from her collections made in Macon County (1934).

GRANT, FRANCIS R. (. . . - . . .). A student of Stella Hague's at the University of Illinois in the early 1930's, he co-authored a 1931 report of the mosses that he collected from Vermilion County in 1929 and 1930.

HAGUE, STELLA MARY (1871-1959). Botonist at the University of Illinois from 1915 to 1940, she published several comprehensive papers on the mosses and liverworts of Illinois in the 1930's. These studies utilized the then available herbarium collections at both the University of Illinois and the Field Museum as well as new collections made by her and her students. Her interest in the state bryoflora inspired five of her students to collect and also to contribute to our published accounts during a single decade. Later, as "Associate Professor Emerita," she published a paper with Winona Welch which dealt with the sporophytes of *Bryoxiphium*, a moss still unreported from Illinois (1951).
Necrology: Crum, H.A. 1959.

HALL, ELIHU (1822-1882). Resident of Athens, Illinois, his profession was that of a farmer and surveyor. Upon his being elected as Menard County surveyor he was allowed ample time for botanizing in the area. Not only did he aid in the organization of the first Illinois Natural History Society of 1858, but corresponded with the major botanists of his day including Asa Gray, among others. He was a member of the Parry Expedition to Colorado in 1862 and also communicated bryophyte specimens from Texas, Oregon, Kansas, and Missouri to Austin and other systematists. His first love was the bryophytes and lichens but he published only a single work during his lifetime. It was the treatise co-authored with John Wolf, his friend and colleague (see Wolf, 1878).
Bibliography: Ewan, J. 1950.
Necrology: Gray, A. 1884; Milligan, J.M. 1884.
Bryological Eponymy: *Anthoceros hallii* Aust.
Archidium hallii Aust.
Bruchia hallii Aust.
Campylopus hallii Lesq.
Conomitrium hallianum Sull. & Lesq.
Fissidens hallii Aust.
Frullania hallii Aust.
Lophocolea hallii Aust. (Type: Illinois)
Orthotrichum hallii Sull. & Lesq.
Radula hallii Aust.

HATCHER, RAYMOND EDWARD (1930-1967). Born in Murphysboro, Illinois, he developed his botanical interest while an undergraduate student at Southern Illinois University and published his first bryological work in 1952. He completed graduate studies with Margaret Fulford at the University of Cincinnati and was awarded the Ph.D. in 1959. A continuing appointment at the University of Wisconsin-Milwaukee followed a one year teaching position at the University of Tennessee. His further work with Illinois bryophytes was restricted to culture studies of select southern Illinois Hepaticae along with other regional and exotic taxa.
Necrology: Fulford, M. & P. Whitford. 1968. (portr.)

HILL, ELLSWORTH JEROME (1833-1917). Appointed pastor of the Presbyterian Church of Homewood in 1863 and a sometime high school teacher, he corresponded with various botanists of his day including Asa Gray and Serino Watson. Hill devoted the last decade of his life to the mosses of the Chicago region and published several papers (1902, 1905, 1907, 1909, 1914, 1916) which included new moss reports for Illinois. According to Agnes Chase (1917) he left her a manuscript with detailed descriptions of 133 species of Illinois mosses. This unpublished paper, however, is not among her memorabilia at the Smithsonian (Nicholson, 1975).
Necrology: Chase, A. 1917. (portr.); Hill, A.E. 1917. (portr.).

HOLMES, STELLA A. (*SEE* Barrick).

JAMES, THOMAS POTTS (1803-1882). (*SEE* Lesquereux).

JONES, GEORGE NEVILLE (1903-1970). Noted Illinois botanist and author of the first comprehensive flora of Illinois (1945). He took his doctorate from the University of Washington under the tutelage of T.C. Frye. During his student years under the influence of both Drs. Frye and Clark, he became interested in bryophytes and published several articles dealing with moss floristics. His major bryological publication was the chapter on the Grimmiaceae in Grout's *"Moss Flora of North America"* (1933). Following his appointment at the University of Illinois in 1939, his continued interest in bryophytes was reflected by the inclusion of numerous Illinois specimens in the herbarium. His only Illinois bryological publication, however, was on the discovery of *Merceya* in the state (1961).
Bibliography: Evers, R.A. 1970. (portr.); Payne, W.W. & R.A. Evers, 1971. (portr.).

LESQUEREUX, CHARLES LEO (1806-1899). Famed bryologist and paleobotanist who began work with William Sullivant at Columbus, Ohio in 1848 on a North American moss flora. Not only did Wolf and Hall communicate Illinois specimens for their study, but in addition submitted their numerous collections from Colorado (Wolf & Hall) Oregon (Hall) and Texas (Hall). The flora was finally completed by Lesquereux and T.P. Jones of Cambridge, Massachusettes some 12 years after the death of Sullivant. James began working with Lesquereux in making the detailed microscopic analyses for him due to his partially failing eyesight. This work was not published until 1884, two years after the death of James. Of the 900 species included, 17 were specifically cited as Illinois collections.
Bibliography: Rodgers, A.D. III. 1940; Smith, A.M. 1909. (portr.).

MONTGOMERY, CHARLES EDGAR (1884-. . .). Doctoral student at the University of Chicago, he took his Ph.D. in 1930 and published a detailed account on the ecology of mosses (1931). The field work for this study was centered in the Dixon quadrangle region of northern Illinois. He served as head of biology at N.I.U., DeKalb from 1920 until his retirement in 1952.

MORROW, JEAN S. (1901-). Student at Western Illinois University during the early 1950's. She was influenced by botanist R.M. Myers to survey the McDonough County mosses and published her account in 1952.

NELSON, NELSON LAWRENCE T. (1862-1932). Botanist who was associated with at least one dozen colleges and school systems during his teaching career, and avid bryophyte collector. His nearly 7,000 moss specimens are deposited in the American Bryological and Lichenological Society moss herbarium (ABSM) at Duke University. Of these, a number are from Illinois. His only publication was a check list of the St. Louis area (1911). This included one hepatic and 13 mosses from nearby Illinois.
Bibliography: Gier, L.J. 1953. (portr.).

O'FLAHERTY, LARRANCE M. (1941-). Doctoral student of Harry T. Phinney at Oregon State and botanist at Western Illinois University since 1968. His field studies in west-central Illinois have resulted in the recent addition of two *Sphagnum* taxa to the Illinois flora (1975, 1978).

PATTERSON, HARRY NORTON (1853-1919). Oquawka, Illinois newspaper publisher, printer and avid botanist. He printed herbaria and exsiccatae labels as well as exchange lists for plant collectors throughout the country. His publication on the plants in the vicinity of Oquawka (1874) included an appended list of 38 moss taxa determined by T.P. James. His herbarium was acquired in 1900 by the Field Museum of Natural History (Ewan, 1950).
Bibliography: Ewan, J. 1950. (portr.).

REDFEARN, PAUL LESLIE, JR. (1926-). Doctoral student of Ruth Breen's at Florida State University and botanist at Southwest Missouri State University. He has published a series of papers

on bryophytes of the Interior Highlands including additions to the Illinois flora (1966, 1968, 1972) based in part on his numerous collections from southern Illinois. At present he is working on an updated, comprehensive moss flora for the entire state of Illinois which will contain original drawings of each taxon.

REICHLE, DAVID E. (1938-). A Ph.D. student at Northwestern University in the early 1960's. Although his primary interest was in radiation and animal ecology, he published a study on bryophyte succession in Volo Bog with W.T. Doyle (1965).

RICHARDS, DONALD (. . . -). Associate of the Field Museum, he published an account of the bryophytes of Starved Rock in 1940. This was based not only on his personal collections, but likewise included the available herbarium specimens.

SKOREPA, ALLEN CHARLES (1941-). While a master's student of Robert Mohlenbrock's at Southern Illinois University his prime interest lay with the lichens although he published an account of Illinois hepatics (1968) and included a few mosses in a paper co-authored with J. Snider in 1967. He later took his Ph.D. from the University of Tennessee under the direction of A.J. Sharp. His dissertation dealt with the lichens of southern Illinois.

SNIDER, JERRY A. (1937-). As an undergraduate student at Southern Illinois University he published a study of the genus *Sphagnum* in Illinois (1970). He completed his master's with C.R. Bell at the University of North Carolina and took his Ph.D. at Duke University under Lewis Anderson. He is presently a botanist at the University of Cincinnati, specializing in bryology.

SPESSARD, LINDA L. (1947-). As a student of Charles Arzeni's at Eastern Illinois University during the early 1970's, she published on several mosses new to Illinois (1975) and a paper on the bryophytes of Shelby County based on her master's thesis. She then pursued the Ph.D. with A.J. Sharp at the University of Tennessee.

STOTLER, RAYMOND EUGENE (1940-). Doctoral student of Margaret Fulford's at the University of Cincinnati and botanist at Southern Illinois University since 1969. He has published on saxicolous bryophyte associations (1976, 1977) in southern Illinois and on the hepatics and anthocerotes of Lusk Creek (1979). At present he is working on an updated, comprehensive liverwort and hornwort flora for the entire state which will contain original drawings of each species.

SULLIVANT, WILLIAM STARLING (1803-1873). The premier North American bryologist and probably the most outstanding microscopist of his day (vide: Rodgers, 1940). He prepared the bryophyte account in Gray's *"Manual"* in both the first and second editions. Separates were titled *"Musci and Hepaticae of the Northern United States."* He began a manual of the mosses of North America with Lesquereux which included many Illinois specimens and was completed after his death by Lesquereux (See above).
Bibliography: Rodgers, A.D. III. 1940. (portr.).

TAYLOR, ARAVILLA MEEK (. . . - . . .). Ecologist who took his Ph.D. at the University of Chicago in 1919, he published a comprehensive study of moss succession based on field studies in the numerous habitats of the Chicago region (1920a). At the same time, he authored a separate paper which alphabetically listed the 81 mosses observed within these 20 varied habitats (1920b). He instructed at five different schools during his teaching career, remaining at Lake Erie College in Painesville, Ohio from 1924 until his retirement in 1947.

UNDERWOOD, LUCIEN MARCUS (1853-1907). Educated at Syracuse, he began his botanical studies on ferns in 1875 but did his master's thesis in geology in 1878. After taking the position of Professor of Natural Science at Hedding College in Abington, Illinois in 1880, he quickly moved that same year to Illinois Wesleyan University, Bloomington, as Professor of geology, where he remained for three years. There he became interested in the Hepaticae having access to a set of Austin's *"Exsiccatae"* which was housed at the Illinois State Laboratory of Natural History near the university. His manual of the North American Hepatics was finished after he had returned to New York and taken a position at Syracuse. He sent it back to Illinois for publication in the Bulletin of the Natural History Society (1884). Not only did this publication include Illinois hepatics but he likewise included Illinois species in the liverwort section of Gray's *"Manual,"* sixth edition (1890). Bryophytes had been treated previously only in the first and second editions but no Illinois specimens were tabulated in those. The Underwood treatment of Hepaticae was the only other inclusion of these cryptogams among the now nine editions of Gray's *"Manual."* Underwood initiated a publication titled *"Index Hepaticarum"* to expand his study of the liverworts of all of North America but only the bibliography section was ever completed and published (1893). His interest turned again to the ferns at the expense of further bryological studies. His Illinois bryophyte collections are now extant at the New York Botanical Garden (NY).
Necrology: Curtis, C.C. 1908. (portr.); Haynes, C.C. 1908; Howe, M.A. 1908.
Bryophytic Eponymy: *Gyrothyra underwoodiana* Howe.

VASEY, GEORGE (1822-1893). Physician and botanist who settled in Ringwood, Illinois in 1848. He published our first so-titled bryophyte account of Illinois mosses which appeared in print in the same volume as Brendel's list of mosses in the vicinity of Peoria. While serving as curator of the Natural History Museum of the State Normal School, he was appointed botanist and curator of the United States Department of Agriculture and left Illinois in 1882.

VAUGHAN, RUPERT HAROLD (. . . - . . .). Teacher at Sullivan Township High School, he prepared a check list of the bryophytes from his collections in Moultrie and Clark Counties (1940, 1941). His duplicate specimens are deposited in Carbondale (ABSH), Urbana (ILL), and Ann Arbor (MICH).

WEST, VERONICA MARIE (NEE BAGADONAS) (1949-). As a master's student of Raymond Stotler's at Southern Illinois University she published a paper on saxicolous bryophyte associations of Panther's Den (1977).

WINTERRINGER, GLEN SPELMAN (1906-1974). Botanist and former curator of the Illinois State Museum (ISM), he co-authored a paper that treated various moss and lichen taxa in an ecological study of rock ledge vegetation (1956).

WOLF, JOHN (1820-1897). Government assayer, naturalist, and linguist who settled in Canton, Illinois in 1960. He was called "Professor" by the residents. Wolf established a museum in Canton and pursued his hobbies of botany, geology, and entomology. He was a botanist with the Wheeler Expidition in Colorado (1873) and as an enthusiastic collector he communicated many specimens of bryophytes to Austin, James, Lesquereux, and Sullivant. His acquaintance with Elihu Hall and their combined interest in bryophytes and lichens led to the first detailed account of these in Illinois (1878). This was based largely on their collections from Fulton (Wolf) and Menard (Hall) Counties although four southern Illinois counties had been collected by Wolf (Jackson, Union, Johnson, and Pulaski). They also, no doubt, included the collections of George Vasey and perhaps of Brendel as evidenced from the county citations in their paper.
Bibliography: Middleton, M. 1940. (portr.).
Bryological Eponymy: *Acaulon wolfii* James
Weisia wolfii Lesq. & James

WUNDERLIN, R.P. (1939-). While a student at Southern Illinois University his interest was primarily with higher plant systematics although he published an account of Carroll County mosses (1967) based on literature reports and personal collections.

ZALES, WILLIAM M. (1944-). As a master's student of Charles Arzeni's at Eastern Illinois University, he published an account of the bryophytes of Goose Lake Prairie (1971). He took his Ph.D. at the University of British Columbia under the direction of W.B. Schofield and presently teaches at Joliet Junior College.

ZEHR, DOUGLAS RAY (1952-). A student of Raymond Stotler's at Southern Illinois University, he published an autecological study of selected bryophytes in three sandstone canyons in Illinois (1977) and a phenological study of five Illinois bryophytes (1979).

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I would like to express thanks to the following for contributing bibliographic information: Dr. Charles Arzeni, Eastern Illinois University; Dr. Zane Carothers, University of Illinois; Dr. John Engel, Field Museum; Dr. Robert Henry, Western Illinois University.

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_____ and WELCH, W.H. 1951. Observations regarding scarcity of sporophytes in *Bryoxiphium norvegicum*. Bryologist 54:214-215.

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CHECKLIST OF THE MOSSES OF ILLINOIS

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ABSTRACT

Forty-two families, 115 genera, 321 species, and 20 varieties are reported from Illinois based upon examination of herbarium collections and literature citations. Distributions are recorded by counties and geographical areas. Present records indicate many areas of the state need more critical collecting. A bibliography on the mosses of Illinois is included.

INTRODUCTION

The check list is based upon examinations of moss collections at the Chicago Museum of Natural History, the University of Illinois, Southern Illinois University at Carbondale, Northern Illinois University, the Missouri Botanical Garden and Southwest Missouri State University. Additionally, many collections were provided by recent collectors for study. The cooperation of the curators of these herbaria and recent collectors is gratefully acknowledged. Species reported in the early literature though not examined by us are included whenever they seem plausible. As with any check list, we intend this list not to be the last word, or even the most accurate one, but rather a guide to stimulate more critical study of mosses in the state.

The distribution of each taxon is listed by area (Figure 1) and by county within each area. We have divided Illinois into six areas that are characterized below (Mohlenbrock, 1975; Jones, 1963).

Area 1 encompasses in the north the Wisconsin Driftless Division, an upland area with Ordivician Silurian limestone, dolomite, and shale exposures and the Rock River Hill Country Division that is covered with glacial drift. Some sandstone exposures are located in the southeastern part of the latter division. The southern part of this area includes the Western and Green River Lowlands Sections of the Grand Prairie Division. The Western Section consists of level to rolling uplands derived from older dissected Illinoian drift while the Green River Lowland section is composed of outwash plains formed by glacial melt. On the western edge of this area occurs the Middle and Upper Mississippi River Bottomlands, the Illinois River Bottomlands Divisions and the Illinois and Mississippi River Sand Hills Division. The Middle Mississippi section is heavily dissected and bluffs of limestone and sandstone are common. The Upper Mississippi Section consists mainly of broad floodplains and gravel terraces. The topography of the Sand Hills Division is one of level to rolling plains of sand which often form dunes.

Area 2 includes the Northeastern Morainal Division, an area characterized by deep glacial drift with Ordivician and Silurian limestone outcrops along streams. Fens, marshes, sedge meadows, and bogs are

common. The southern part of area 2 is occupied by the Grand Prairie Section of the Grand Prairie Division and it is generally level and covered by soil developed from loess, lakebed sediments, and glacial outwashes.

Area 3 includes primarily the Western Forest-Prairie Division. It is a strongly dissected glacial till plain with limestone outcroppings. Sandstone, and shale frequently occur along major streams and ravines. Along the western edge of the Illinois River and Mississippi River Sand Areas Division (see above), the Upper Middle Mississippi Borderland Division occur. Bottomlands characterize the former and riverbluffs of limestone the latter.

Area 4 includes primarily the Springfield and Grand Prairie Sections of the Grand Prairie Division (see above). Along the eastern portion of this area is the Wabash Border Division which is characterized by loess-covered uplands and bottomlands along the Wabash River.

Area 5 lies mostly in the Southern Till Plain Division. It is an area composed of dissected Illinoian glacial till. On the east it is bordered by the Wabash Border Division and on the west by the Lower Mississippi River Bottomlands Division and the Northern and Central Sections of the Ozark Division. Sink holes and steep limestone bluffs are found in these latter sections.

Area 6 encompasses parts of five Divisions. The Shawnee Hills Division consists of rugged topography with numerous bluffs and ravines. Sandstone exposures are common. The Ozark Division consists of a dissected plateau with steep limestone bluffs along the Mississippi River and many ravines exposing limestone or sandstone. The Bottomlands Section of the Wabash Division and the Lower Mississippi River Bottomlands Division consists mainly of flood plain areas. The Coastal Plain Division is a region of swampy bottomlands on a broad floodplain.

Nomenclature for the species listed below generally follows Crum, Steere, and Anderson (1973). The major exception occurs in the genus *Amblystegium (sensu lato)* which includes the genera *Hygroamblystegium* and *Leptodictyum* of other authors.

LIST OF SPECIES

AMBLYSTEGIACEAE

Amblystegium

brevipes Card. & Ther. 1 (Ogle), 2 (DeKalb), 3 (Hancock, Peoria), 4 (Cass, Champaign, Logan), 5 (Shelby).

fluviatile (Hedw.) B.S.G. 1 (Ogle), 2 (Cook, Dekalb, DuPage, LaSalle, Will), 3 (Adams, Hancock, Mc Donough), 5 (Clark, Monroe), 6 (Jackson).

juratzkanum Schimp. 1 (Jo Daviess), 2 (Cook, Kane, LaSalle), 3 (Fulton, Hancock), 4 (McLean, (Tazewell,), 5 (Clark, Shelby), 6 (Johnson, Pope, Union).

kochii B.S.G. 1 (Carroll, Lee, Ogle, Winnebago), 2 (Cook, DeKalb, DuPage, Kane, Lake, McHenry), 3 (Hancock, Henderson, McDonough, Peoria), 4 (Cass, Champaign, Christian, DeWitt, Douglas, Livingston), 5 (Clark, Shelby), 6 (Johnson, Saline, Union, Williamson).

noterophilum (Sull. & Lesq.) Holz. 2 (Cook, LaSalle, Will).

riparium (Hedw.) B.S.G. 1 (Carroll, Marshall, Rock Island, Winnebago), 2 (Cook, DeKalb, Grundy, Kane, Lake, LaSalle, Will), 3 (Fulton, Hancock, Peoria), 4 (Cass, Champaign, Coles, Livingston, Macon, Mason, Menard, Moultrie), 5 (Clark, Crawford, Shelby), 6 (Jackson, Johnson, Pulaski, Union, Williamson).

serpens (Hedw.) B.S.G. 1 (Carroll, Jo Daviess, Ogle, Rock Island, Winnebago), 2 (Cook, DeKalb, Kendall, Lake, McHenry), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria), 4 (Champaign, Coles, DeWitt, Livingston, Macon, Menard, Moultrie, Vermilion), 5 (Clark, Crawford, Shelby), 6 (Jackson, Johnson, Pope, Union).

tenax (Hedw.) C. Jens. var. *tenax*. 1 (Carroll, Jo Daviess, Rock Island, Whiteside), 2 (Cook, Lake, LaSalle, McHenry, Will), 3 (Adams, Fulton, Hancock, Henderson, Peoria), 4 (Cass, Coles, Menard, Vermilion, Woodford), 5 (Clark, Shelby), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Pope, Union).

var. *spinifolium* (Schimp.) Jens. 2 (Cook), 3 (Hancock).

trichopodium (Schultz.) Hartm. 1 (Carroll, Lee, Ogle, Winnebago), 2 (Cook, DeKalb, DuPage, Grundy, Kane, McHenry, Will), 3 (Hancock, Henderson, McDonough, Peoria), 4 (Cass, Coles, Livingston), 5 (Clark, Shelby), 6 (Saline, Union, Williamson).

varium (Hedw.) Lindb. var. *varium* fo. *varium*. 1 (Bureau, Carroll, Jo Daviess, Ogle, Rock Island, Whiteside), 2 (Cook, DeKalb, Grundy, Kane, Lake, LaSalle, McHenry, Will), 3 (Adams, Fulton, Hancock, Jersey, McDonough, Peoria, Warren), 4 (Cass, Champaign, Cole, Macon, Menard, Moultrie, Livingston, Vermilion), 5 (Clark, Crawford, Franklin, Jefferson, Shelby), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Union).

fo. *parvulum* (Aust.) Grout. 3 (McDonough), 4 (Cass)

var. *ovatum* Grout. 1 (Jo Daviess), 3 (Warren).

Calliergon

cordifolium (Hedw.) Kindb. 2 (Lake).

Calliergonella

cuspidata (Hedw.) Loeske. 2 (Lake), 4 (Coles), 5 (Clark).

Campylium

chrysophyllum (Brid.) J. Lange var. *chrysophyllum*. 2 (Cook, Kane, Lake, Will), 3 (Adams, Fulton, Hancock, McDonough, Peoria), 4 (Coles, Macon, Menard, Moultrie), 5 (Clark, Crawford, Fayette, Franklin, Jefferson), 6 (Gallatin, Hardin, Jackson, Pope, Union, Williamson).

var. *brevifolium* (Ren. & Card.) Grout. 5 (Clark).

hispidulum (Brid.) Mitt. var. *hispidulum*. 1 (Carroll, Winnebago), 2 (Cook, Kane, Lake, Will), 3 (Adams, Fulton, Hancock, McDonough, Peoria), 4 (Champaign, Coles, Mason, McLean, Menard, Moultrie), 5 (Clark, Crawford, Effingham, Fayette, Franklin, Randolph, Shelby, Wayne).

var. *sommerfeltii* (Myr.) Lindb. 3 (Fulton).

polygamum (B.S.G.) C. Jens var. *minus* (Schimp.) Roth. 1 (Ogle).

radicale (P. -Beauv.) Grout. 2 (Cook, McHenry, Will), 3 (Fulton), 4 (Menard).

stellatum (Hedw.) C. Jens. 2 (Cook, Lake), 4 (Coles).

Cratoneuron

filicinum (Hedw.) Spruce. 1 (Carroll, Grundy, Jo Daviess, Winnebago), 2 (DeKalb, Lake, McHenry, Will), 3 (Adams, Fulton), 4 (Coles, Menard, Tazewell), 5 (Clark).

Drepanocladus

aduncus (Hedw.) Warnst. var. *aduncus*. 1 (Jo Daviess, Winnebago), 2 (Cook, DeKalb, Grundy, Lake, McHenry, Will), 3 (Fulton, Peoria), 4 (Menard, Tazewell).

var. *kneiffii* (B.S.G.) Mönk. 2 (Lake, Will), 4 (Champaign), 5 (Shelby).

var. *polycarpus* (Bland. *ex* Voit) Roth. 1 (Lee, Ogle), 2 (Cook, Lake, Will), 3 (Fulton).

exannulatus (B.S.G.) Warnst. 2 (Lake), 6 (Johnson).

fluitans (Hedw.) Warnst. 2(Cook, Lake).

sendtneri (Schimp.) Warnst. 1(Winnebago).

uncinatus (Hedw.) Warnst. 2 (Cook, Lake, Will), 4 (Menard).
vernicosus (Lindb.) Warnst. 2 (Lake).

Hygrohypnum
alpestre (Hedw.) Loeske. 3 (Fulton), 4 (Menard).
ochraceum (Turn. *ex* Wils.) Loeske var. *ochraceum*. 6 (Pope).

Platydictya
confervoides (Brid.) Crum. 1 (Carroll, Ogle), 2 (Cook), 3 (Hancock), 4 (Coles), 6 (Jackson, Saline).
jungermannioides (Brid.) Crum. 2 (LaSalle), 4 (Menard).
subtile (Hedw.) Crum. 1 (Carroll, Jo Daviess), 2 (Cook, LaSalle), 4 (Menard), 5 (Franklin), 6 (Union).

ARCHIDIACEAE

Archidium
alternifolium (Dicks. *ex* Hedw.) Schimp. 2 (Cook), 3 (Fulton), 4 (Sangamon).
ohioense Schimp. *ex* C. Muell. 2 (Cook), 4 (Menard).

AULACOMNIACEAE

Aulacomnium
androgynum (Hedw.) Schwaegr. 2 (Lake), 3 (Schuyler).
heterostichum (Hedw.) B.S.G. 1 (Henry, Ogle), 2 (Cook, Lake, LaSalle, McHenry), 3 (Calhoun, Fulton, Greene, Hancock, McDonough), 4 (Champaign, Coles, Menard, Moultrie, Vermilion), 5 (Clark, Effingham, Fayette, Franklin, Randolph, Richland, Shelby), 6 (Alexander, Hardin, Jackson, Johnson, Pope, Union, Williamson).
palustre (Hedw.) Schwaegr. 1 (Ogle), 2 (Cook, Grundy, Kane, Lake), 4 (Case), 5 (Clark, Crawford, Jasper), 6 (Johnson, Pope, Union).

BARTRAMIACEAE

Bartramia
pomiformis Hedw. var. *pomiformis*. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, Lake, LaSalle, McHenry), 3 (Fulton, Hancock, McDonough, Peoria), 4 (Champaign, Coles, Menard, Vermilion), 5 (Clark, Randolph, Shelby), 6 (Gallatin, Jackson, Johnson, Pope, Saline, Union, Williamson).
var. *elongata* Turn. 2 (Lake).

Philonotis
caespitosa Jur. 6 (Jackson).
fontana (Hedw.) Brid. *fontana*. 2 (Cook, Lake, LaSalle), 3 (Schuyler), 4 (Champaign, Menard), 5 (Randolph), 6 (Gallatin, Jackson, Johnson, Pope).
longiseta (Michx.) Britt. 4 (Menard).
marchica (Hedw.) Brid. 2 (Cook), 3 (Fulton, Hancock), 6 (Pope).
muhlenbergii (Schwaegr.) Brid. 2 (Lake), 3 (Fulton).

Plagiopus
oederiana (Sw.) Limpr. 1 (Ogle).

BRACHYTHECIACEAE

Brachythecium

acuminatum (Hedw.) Rau & Herv. var. acuminatum. 1 (Carroll, Lee, Ogle, Stephenson), 2 (Cook, DeKalb, Kane, Lake, Will), 3 (Adams, Fulton, Hancock, Henderson, Peoria), 4 (Cass, Champaign, Coles, Macon, Menard, Vermilion), 5 (Clark, Hamilton, Marion, White), 6 (Jackson, Pope, Union).

acutum (Mitt.) Sull. 2 (Cook, Will), 4 (Menard).

calcareum Kindb. 3 (Henderson, Peoria), 4 (Menard).

campestre (C. Muell.) B.S.G. 3 (McDonough), 5 (Shelby).

collinum (Schleich. *ex* C. Muell) B.S.G. Reported by Wolf & Hall (1878), no locality given.

digastrum C. Muell. & Kindb. *ex* Macoun & Kindb. 2 (Lake).

oxycladon (Brid.) Jaeg. &Sauerb. var. *oxycladon*. 1 (Carroll, Jo Daviess, Ogle, Rock Island, Winnebago), 2 (Cook, DeKalb, Kane, Lake, LaSalle, Will), 3 (Adams, Calhoun, Fulton, Hancock, McDonough, Mercer, Peoria), 4 (Champaign, Coles, Macon, Menard, Moultrie, Vermilion, Woodford), 5 (Clark, Crawford, Franklin, Randolph, St. Clair, Shelby), 6 (Jackson, Johnson, Pulaski, Union, Williamson).

var. *dentatum* (Lesq. & James) Grout. 5 (Clark).

plumosum (Hedw.) B.S.G. 2 (LaSalle), 4 (Coles), 5 (Clark), 6 (Gallatin, Jackson, Union).

reflexum (Web. & Mohr.) B.S.G. 3 (Hancock).

rivulare B.S.G. 2 (DeKalb, Kane, LaSalle), 3 (Fulton, Peoria), 4 (Menard, Tazewell), 5 (Clark, Marion).

rutabulum (Hedw.) B.S.G. 1(Ogle), 2 (Cook, Kane, Lake), 3 (Adams, Fulton), 5 (Crawford).

salebrosum (Web. & Mohr.) B.S.G. 1 (Carroll, Jo Daviess, Ogle, Winnebago), 2 (Cook, DeKalb, Kane, Lake, LaSalle, McHenry, Will), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria), 4 (Cass, Champaign, Coles, Livingston, Macon, Menard, Piatt, Tazewell, Vermilion), 5 (Bond, Clark, Crawford, Monroe, Shelby), 6 (Jackson, Johnson, Saline, Union).

serrulatum (Hedw.) Robins. 1 (Carroll, Jo Daviess, Ogle, Rock Island, Winnebago), 2 (Cook, DeKalb, Grundy, Kankakee, Lake, LaSalle), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria), 4 (Cass, Champaign, Coles, Macon, Menard, Moultrie, Piatt, Tazewell, Vermilion), 5 (Clark, Franklin, Jasper, Marion, Shelby), 6 (Alexander, Gallatin, Jackson, Johnson, Union, Williamson).

Bryhnia

graminicolor (Brid.) Grout. 1 (Carroll, Ogle), 2 (Cook, LaSalle), 3 (Adams, Fulton, Hancock, McDonough, Peoria), 4 (Cass, Coles, Menard, Vermilion), 5 (Clark, Shelby), 6 (Jackson, Union).

novae-angliae (Sull. & Lesq. *ex* Sull.) Grout. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook), 5 (Crawford).

Bryoandersonia

illecebra (Hedw.) Robins. 2 (Cook, Kane, LaSalle), 3 (Hancock, McDonough, Peoria), 4 (Coles, Menard, Moultrie), 5 (Clark, Shelby), 6 (Gallatin, Jackson, Johnson, Pope, Union, Williamson).

Homalotheciella

subcapillata (Hedw.) Broth. 3 (Fulton), 4 (Menard).

Rhynchostegiella

compacta (C. Muell) Loeske. 1 (Jo Daviess), 5 (Clark), 6 (Jackson, Pope).

Rhynchostegium

hians (Hedw.) Delong. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, DeKalb, DuPage, Kendall, Lake, Will), 3 (Adams, Fulton, Hancock, Mercer, Peoria), 4 (Livingston, Macon, Menard, Woodford), 5 (Clark, Franklin, Shelby), 6 (Jackson, Union).

pulchellum (Hedw.) Robins var. *pulchellum*. 1 (Carroll, Ogle), 2 (Cook, Kane, McHenry), 3 (McDonough, Peoria), 4 (Cass, Macon, Menard), 5 (Franklin, Jefferson, Marion), 6 (Gallatin, Jackson, Union).

var. *praecox* (Hedw.) Dix. 1 (Winnebago), 3 (Hancock), 5 (Randolph), 6 (Gallatin, Jackson, Union).

riparioides (Hedw.) Card. *in* Tourret. 1 (Ogle), 6 (Hardin).

Tomenthypnum

nitens (Hedw.) Loeske. 2 (Lake), 3 (Fulton), 4 (Menard).

BRYACEAE

Bryum

angustirete Kindb. *ex* Macon. 1 (Henry, Rock Island), 2 (Cook, DeKalb), 3 (Fulton), 4 (Menard), 5 (Clark).

argenteum Hedw. 1 (Carroll, Jo Daviess, Ogle, Rock Island), 2 (Cook, DeKalb, DuPage, LaSalle, McHenry), 3 (Adams, Brown, Fulton, Hancock, Peoria), 4 (Cass, Champaign, Coles, Macon, Menard, Moultrie, Vermilion), 5 (Clark, Fayette, Jefferson, Shelby), 6 (Jackson, Pope, Union, Williamson).

bicolor Dicks. 6 (Union).

caespiticium Hedw. 1 (Carroll, Henry, Jo Daviess, Ogle. Rock Island), 2 (Cook, DuPage, Grundy, Lake, McHenry, Will), 3 (Brown, Fulton, McDonough, Peoria), 4 (Cass, Coles, Macon, Menard, Piatt, Vermilion), 5 (Clark, Shelby).

capillare Hedw. 2 (Cook), 4 (Menard), 5 (Gallatin, Jackson).

creberrimum Tayl. 1 (Carroll), 2 (Cook, DuPage, Kankakee, LaSalle, Will), 3 (Adams, Fulton, Hancock, McDonough), 4 Iroquois, Mason), 5 (Effingham, Jasper, Randolph, Shelby), 6 (Gallatin, Jackson).

lisae DeNot var. *cuspidatum* (B.S.G.) Marg. 3 (Peoria), 4 (Tazewell).

lonchocaulon C. Muell. 2 (Cook, Lake).

pseudotriquetrum (Hedw.) Gaertn., Meyer, & Sauerb. var. *pseudotriquetrum*. 1 (Jo Daviess, Ogle, Stark, Winnebago), 2 (Cook, Kane, Lake, LaSalle, Will), 3 (Adams, Fulton, Hancock, McDonough, Peoria), 4 (Cass, Coles, Menard), 5 (Clark, Randolph, Shelby), 6 (Gallatin, Jackson, Pope, Union).

uliginosum (Brid.) B.S.G. 3 (Fulton, Peoria), 4 (Champaign, Menard).

Leptobryum

pyriforme (Hedw.) Wils. 1 (Rock Island), 2 (Cook, DeKalb, Grundy, LaSalle), 3 (Fulton), 4 (Champaign, Coles, Mason, Menard), 5 (Clark, Franklin), 6 (Jackson, Union).

Pohlia

annotina (Hedw.) Lindb. var. decipiens Loeske. 2 (LaSalle), 3 (Fulton).

atropurpurea (Wahlenb.) Lindb. 3 (Fulton), 4 (Menard).

carnea (Turn.) Lindb. 3 (Fulton).

nutans (Hedw.) Lindb. 1 (Ogle), 2 (Cook, Grundy, Lake, LaSalle, McHenry), 3 (Brown, Fulton, Hancock, McDonough), 4 (Coles, Mason, Menard, Moultrie, Vermilion), 5 (Fayette, Randolph, Shelby, Washington), 6 (Gallatin, Jackson, Johnson, Pope, Saline, Union).

wahlembergii (Web. & Mohr.) Andr. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, Lake), 3 (Adams, Fulton, Hancock, Schuyler), 4 (Coles, Menard), 5 (Clark, Hamilton, Shelby), 6 (Union).

Rhodobryum

roseum (Hedw.) Limpr. 1 (Carroll, Ogle, Winnebago), 2 (Cook, Kane, LaSalle, McHenry), 3 (Adams, Calhoun, Fulton, Hancock, Henderson, Peoria), 4 (Coles, Macon, Menard, Moultrie), 6 (Union).

BUXBAUMIACEAE

Buxbaumia
aphylla Hedw. 6 (Pope).

Diphyscium
foliosum (Hedw.) Mohr. 4 (Coles), 5 (Clark, Randolph), 6 (Gallatin, Hardin, Jackson, Johnson, Pope, Saline, Union, Williamson).

CALYMPERACEAE

Syrrhopodon
texanus Sull. 6 (Johnson).

CLIMACEAE

Climacium
americanum Brid. 1 (Carroll, Jo Daviess, Ogle, Rock Island, Winnebago), 2 (Cook, DeKalb, Kane, Lake, LaSalle, McHenry), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria, Warren), 4 (Champaign, Coles, Mason, Menard), 5 (Clark, Effingham, Fayette, Franklin, Jasper, Randolph, Shelby), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Massac, Pope, Pulaski, Saline, Union, Williamson).
dendroides (Hedw.) Web. & Mohr. 2 (Cook, Lake), 3 (Adams), 4 (Menard).

CRYPHAEACEAE

Foresstroemia
ohioensis (Sull.) Lindb. 6 (Pulaski).
trichomitria (Hedw.) Lindb. 4 (Coles), 5 (Clark), 6 (Jackson).

DICRANACEAE

Brothera
leana (Sull.) C. Muell. 2 (LaSalle), 3 (Fulton, Schuyler), 4 (Champaign, Coles), 6 (Jackson, Pope, Saline, Union).

Bruchia
donnelli Aust. 3 (Fulton).
flexuosa (Sw. *ex* Schwaegr.) C. Muell. 1 (Stark), 6 (Gallatin, Jackson, Pulaski).
hallii Aust. 3 (Fulton).
sullivantii Aust. 1 (Stark), 2 (Lake, Grundy), 5 (Jasper), 6 (Jackson).
texana Aust. 1 (Stark).

Campylopus
flexuosus (Hedw.) Brid. 3 (Schuyler).

Dicranella
heteromalla (Hedw.) Schimp. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, Kane, LaSalle, Will), 3 (Fulton, Greene, Hancock, McDonough, Peoria), 4 (Champaign, Coles, Menard, Moultrie), 5 (Clark, Franklin, Randolph, St. Clair, Shelby), 6 (Alexander, Gallatin, Jackson, Johnson, Pope, Union, Williamson).

rufescens (With.) Schimp. 1 (Carroll, Jo Daviess, Ogle), 3 (Fulton), 4 (Coles, Menard), 5 (Clark), 6 (Gallatin).

varia (Hedw.) Schimp. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, Lake, Will), 3 (Adams, Fulton, Hancock, Peoria), 4 (Cass, Coles, Menard, Moultrie, Vermilion), 5 (Clark, Marion, St. Clair), 6 (Gallatin, Jackson).

Dicranum

bonjeanii DeNot *ex* Lisa. 2 (McHenry, Lake).

condensatum Hedw. 4 (Menard), 5 (Randolph), 6 (Jackson, Pope, Saline, Union).

flagellare Hedw. 1 (Ogle), 2 (Cook), 3 (Fulton), 4 (Coles, Menard), 5 (Clark, Jasper), 6 (Johnson, Pope, Saline).

fulvum Hook. 5 (Randolph), 6 (Gallatin, Jackson, Johnson, Saline, Union, Williamson).

montanum Hedw. 1 (Carroll, Ogle), 5 (Randolph), 6 (Jackson, Johnson, Pope, Williamson).

polysetum Sw. 2 (Lake), 4 (Menard).

scoparium Hedw. 1 (Ogle), 2 (Lake), 3 (Adams, Fulton, Hancock, McDonough, Peoria), 4 (Coles, Macon, Mason, Menard, Moultrie, Piatt), 5 (Hamilton, Lawrence, Randolph), 6 (Gallatin, Jackson, Johnson, Pope, Saline, Union, Williamson).

spurium Hedw. 6 (Jackson, Pope).

Trematodon

longicollis Michx. 6 (Jackson, Union).

DISCELLACEAE

Discelium

nudum (Dicks) Brid. 3 (Fulton).

DITRICHACEAE

Ceratodon

purpureus (Hedw.) Brid. 1 (Carroll, Jo Daviess, Lee, Ogle, Stark, Stephenson, Whiteside, Winnebago), 2 (Cook, DeKalb, DuPage, Grundy, Kane, Kankakee, Lake, McHenry, Will), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria, Schuyler), 4 (Cass, Champaign, Coles, Iroquois, Mason, Menard, Moultrie, Piatt, Woodford), 5 (Clark, Franklin, Jasper, Jefferson, Randolph, Wabash, Washington), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Pope, Saline, Union, Williamson).

Ditrichum

pallidum (Hedw.) Hampe. 1 (Jo Daviess, Ogle, Winnebago), 2 (Cook, Grundy, Lake), 3 (Fulton, Hancock, McDonough, Peoria), 4 (Cass, Champaign, Coles, McLean, Menard, Moultrie, Vermilion), 5 (Clark, Crawford, Effingham, Fayette, Franklin, Jasper, Jefferson, Randolph, Wabash, Washington), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Pope, Saline, Union, Williamson).

pusillum (Hedw.) Hampe. 1 (Ogle), 2 (Cook), 3 (Adams, Fulton, Peoria), 4 (Coles, Macon, Menard, Moultrie, Piatt, Sangamon), 5 (Clark, Shelby), 6 (Gallatin, Jackson, Union, Williamson).

Pleuridium

subulatum (Hedw.) Rabenh. 2 (Cook, DuPage, Will), 3 (Adams, Fulton, Hancock, Peoria), 4 (Coles, Macon, Menard, Moultrie, Piatt, Sangamon), 5 (Clark, Shelby), 6 (Gallatin, Jackson, Union, Williamson).

sullivantii Aust. 6 (Jackson).

ENCALYPTACEAE

Encalypta

ciliata Hedw. 1 (Ogle), 2 (Will).

procera Bruch. 1 (Jo Daviess, Whiteside), 2 (Will).

ENTODONTACEAE

Entodon

brevisetus (Hook. Wils. *ex* Wils.) Lindb. 1 (Henry), 2 (Will), 4 (Champaign, Menard), 5 (Marion).

challengeri (Par.) Card. 2 (Kankakee, Lake), 3 (Fulton, Hancock), 4 (Cass, Champaign, Coles, Macon, Menard), 5 (Clark).

cladorrhizans (Hedw.) C. Muell. 1 (Carroll, Henry, Jo Daviess, Ogle, Putnam), 2 (Cook, DeKalb, Kane, Lake, Will), 3 (Adams, Fulton, Hancock, Henderson, Peoria), 4 (Cass, Champaign, Coles, Macon, Menard, Moultrie, Vermilion), 5 (Clark, Crawford, Marion, Shelby), 6 (Alexander, Jackson, Johnson, Massac, Pope, Union, Williamson).

macropodus (Hedw.) C. Muell. 6 (Union).

seductrix (Hedw.) C. Muell. var. *seductrix.* 1 (Jo Daviess, Ogle, Rock Island, Stark), 2 (Cook, DeKalb, Kane, Kankakee, Lake, LaSalle, McHenry, Will), 3 (Adams, Calhoun, Fulton, Hancock, Henderson, McDonough, Mercer, Peoria), 4 (Cass, Champaign, Coles, Macon, Menard, Moultrie), 5 (Clark, Crawford, Effingham, Fayette, Franklin, Randolph, Shelby), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Massac, Pope, Saline, Union).

sullivantii (C. Muell.) Lindb. 3 (Peoria).

Pleurozium

schreberi (Brid.) Mitt. 1 (Ogle), 3 (Fulton), 4 (Coles, Menard), 5 (Clark, Randolph), 6 (Jackson, Pope).

EPHEMERACEAE

Ephemerum

cohaerens (Hedw.) Hampe. 2 (Cook).

crassinervium (Schwaegr.) Hampe var. *crassinervium* 2 (Cook, DeKalb), 3 (Fulton), 4 (Coles, Menard), 5 (Clark).

var. *texanum* (Grout) Bryan & Anderson. 4 (Coles).

spinulosum Bruch & Schimp. *ex* Schimp. 4 (Coles), 5 (Clark).

FABRONIACEAE

Anacamptodon

splachnoides (F. Froel. *ex* Brid.) Brid. 3 (Fulton, McDonough), 4 (Menard), 6 (Pope).

Clasmatodon

parvulus (Hampe) Hook. & Wils. *ex* Sull. 3 (Peoria), 5 (Franklin), 6 (Alexander, Union).

Fabronia

ciliaris (Brid.) Brid. 3 (Hancock), 4 (Menard).

gymnostoma Sull. & Lesq. *ex* Sull. 3 (Fulton), 4 (Menard).

ravenelii Sull. 4 (Coles).

wrightii Sull. 4 (Menard).

Schwetschkeopsis

fabronia (Schwaegr.) Broth. 1 (Carroll), 6 (Jackson, Pope).

FISSIDENTACEAE

Fissidens

adianthoides Hedw. 1(Jo Daviess, Ogle), 2 (Cook, Kane, McHenry), 3 (Fulton, Peoria), 4 (Menard, Tazewell), 6 (Johnson).

bryoides Hedw. var. *bryoides* 2 (Cook, McHenry, Will), 3 (Fulton, Peoria), 4 (Menard).

var. *incurvus* (Starke *ex* Web. & Mohr.) Roehl. 1 (Carroll).

bushii (Card. & Ther.) Card. & Ther. 3 (McDonough), 5 (Shelby), 6 (Hardin, Johnson).

cristatus Wils. *ex* Mitt. 1 (Carroll, Winnebago), 2 (Cook, Lake, LaSalle, Will), 3 (Hancock), 4 (Coles, 5 (Clark, Richland), 6 (Jackson, Johnson, Saline, Union).

exiguus Sull. 2 (Cook, Will), 3 (Hancock, McDonough), 4 (Coles), 5 (Randolph).

fontanus (B. Pyl.) Steud. 2 (Cook), 3 (Fulton, Peoria), 4 (Vermilion), 6 (Jackson, Johnson, Williamson).

grandifrons Brid. 2 (LaSalle), 3 (Fulton), 6 (Union).

hallianus (Sull. & Lesq. *ex* Aust.) Mitt. 4 (Menard).

minutulus Sull. 1 (Carroll), 2 (LaSalle), 3 (Hancock, McDonough), 5 (Franklin, Jefferson, Monroe, Randolph), 6 (Gallatin, Jackson, Johnson, Pope, Union).

obtusifolius Wils. var. *obtusifolius* 1 (Jo Daviess), 2 (LaSalle), 3 (Fulton, Hancock, Schuyler), 4 (Coles), 5 (Clark).

osmundoides Hedw. 4 (Macon, Moultrie), 5 (Franklin), 6 (Gallatin, Jackson, Johnson, Pope, Union).

pusillus (Wils.) Mild. 6 (Johnson).

subbasilaris Hedw. 2 (Kane, Lake, McHenry), 3 (Fulton, Peoria, Schuyler), 4 (Coles), 5 (Marion), 6 (Jackson, Johnson, Union, Williamson).

taxifolius Hedw. 1 (Ogle), 2 (Cook, DeKalb, LaSalle), 3 (Adams, Brown, Fulton, Hancock, McDonough, Schuyler), 4 (Champaign, Coles, Menard), 5 (Clark, Monroe, Randolph, Shelby), 6 (Gallatin, Jackson, Johnson, Massac, Pope, Union).

viridulus (Sw.) Wahlenb. var. *viridulus*. 1 (Carroll, Ogle), 2 (Cook, Kankakee, LaSalle, Will), 3 (Fulton, Hancock, Peoria, McDonough), 4 (Coles, Menard), 5 (Clark, Franklin, Jefferson, Monroe, Randolph, Shelby), 6 (Gallatin, Hardin, Jackson, Johnson, Union).

FONTINALACEAE

Dichelyma

capillaceum (With.) Myr. 2 (Will), 3 (Fulton).

Fontinalis

filiformis Sull. & Lesq. *ex* Aust. 3 (Fulton), 4 (Mason), 5 (Wabash), 6 (Jackson, Johnson).

dalecarlica Schimp. *ex* B.S.G. 1 (Carroll), 3 (Fulton).

missourica Card. 2 (Cook, Will), 6 (Jackson).

novae-angliae Sull. var. *novae-angliae*. 6 (Gallatin, Pope, Pulaski, Saline, Union, Williamson).

sphagnifolia (C. Muell.) Wijk & Marg. 3 (Fulton), 5 (Marion).

FUNARIACEAE

Aphanorrhegma

serratum (Hook. F. & Wils. *ex* Drumm.) Sull. 3 (Fulton, McDonough), 4 (Coles, Menard), 5 (Clark, Shelby).

Funaria

americana Lindb. 2 (Cook, DeKalb, Will).

flavicans Michx. 1 (Stark), 4 (Cass, Menard), 6 (Gallatin).

hygrometrica Hedw. var. *hygrometrica*. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, DeKalb, Grundy, LaSalle), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria).

microstoma Bruch *ex* Schimp. 4 (Menard).

Physcomitriella

patens (Hedw.) B.S.G. 2 (Will), 3 (Fulton).

Physcomitrium

immersum Sull. 3 (Hancock).

pyriforme (Hedw.) Hampe. 1 (Carroll, Jo Daviess, Ogle, Stark), 2 (Cook, DeKalb, Grundy, Kane, Kankakee, Will), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria, Pike), 4 (Cass, Champaign, Coles, Douglas, Iroquois, Macon, Menard, Moultrie, Tazewell, Vermilion), 5 (Clark, Clay, Crawford, Cumberland, Effingham, Fayette, Franklin, Hamilton, Lawrence, Shelby, Washington), 6 (Gallatin, Hardin, Jackson, Pope, Pulaski, Williamson).

GRIMMIACEAE

Grimmia

apicola Hedw. var. *alpicola*. 2 (Lake, Will), 4 (Menard).

anodon B.S.G. 3 (Hancock).

apocarpa Hedw. var. *apocarpa*. 1 (Carroll, Jo Daviess, Ogle, Rock Island), 2 (Cook, Kane, Lake), 3 (Fulton, Hancock, Peoria), 4 (Cass, Coles, Menard, Moultrie, Vermilion), 5 (Clark, Shelby), 6 (Hardin, Jackson, Johnson, Pope, Union).

var. *stricta* (Turn.) Hook. & Tayl. 3 (Hancock).

calyptrata Hook. *ex* Drumm. 4 (Menard).

laevigata (Brid.) Brid. 1 (Ogle), 5 (Clark, Randolph), 6 (Gallatin, Jackson, Johnson, Pope, Saline, Union, Williamson).

olynei Sull. 6 (Pope).

ovalis (Hedw.) Lindb. 6 (Saline).

pilifera P. -Beauv. 3 (McDonough), 6 (Jackson, Union).

HEDWIGIACEAE

Hedwigia

ciliata (Hedw.) P. -Beauv. 1 (Ogle), 2 (Cook, DeKalb, Lake, LaSalle), 3 (Fulton, Peoria), 4 (Coles, Menard, Moultrie), 5 (Clark, Franklin, Randolph), 6 (Gallatin, Hardin, Jackson, Johnson, Pope, Saline, Union, Williamson).

HOOKERIACEAE

Hookeria

acutifolia Hook. & Grev. 5 (Clark).

HYPNACEAE

Callicladium

haldanianum (Grev.) Crum. 1 (Jo Daviess), 2 (Cook, Lake), 3 (Fulton, McDonough, Peoria), 4 (Champaign, Coles, Menard), 5 (Clark), 6 (Union).

Ctenidium

molluscum (Hedw.) Mitt. 4 (Menard), 6 (Jackson, Pope).

Homomallium

adnatum (Hedw.) Broth. 1 (Carroll, Henry, Jo Daviess, Ogle, Rock Island), 2 (Cook, Kankakee, Will), 3 (Adams, Brown, Fulton, Hancock, Henderson, McDonough), 4 (Cass, Coles, Menard), 5 (Clark), 6 (Gallatin, Jackson, Pope).

Hypnum

curvifolium Hedw. 2 (Cook, Lake), 3 (Fulton, Peoria), 4 (Champaign, Coles, Menard, Vermilion), 5 (Clark, Marion, Randolph), 6 (Gallatin, Jackson, Johnson, Pope, Union).

cupressiforme Hedw. var. *cupressiforme*. 4 (Menard).

imponens Hedw. 2 (Cook; Henry), 3 (Fulton, Peoria), 4 (Champaign, Menard), 5 (Clark, Marion, Randolph), 6 (Gallatin, Jackson, Union).

lindbergii Mitt. 1 (Ogle, Winnebago), 2 (Cook, DeKalb), 3 (Adams, Hancock, Henderson, Peoria), 4 (Coles, Menard, Tazewell, Vermilion), 5 (Clark, Crawford, Franklin, Shelby), 6 (Johnson, Pope).

pallescens (Hedw.) P. -Beauv. 1 (Ogle), 3 (Fulton), 4 (Menard), 5 (Clark).

pratense Koch *ex* Brid. 2 (Lake).

subimponens Lesq. 1 (Ogle), 2 (Peoria).

Isopterygium

distichaceum (Mitt.) Jaeg. & Sauerb. 6 (Pope).

elegans (Brid.) Lindb. 2 (Will), 6 (Gallatin, Jackson, Johnson, Union).

tenerum (Sw.) Mitt. 1 (Jo Daviess), 2 (Cook), 3 (Fulton), 4 (Macon, Menard), 6 (Pope, Union).

Isopterygiopus

muelleriana (Schimp.(Iwats. 3 (Hancock), 5 (Shelby).

Platygyrium

repens (Brid.) B.S.G. 1 (Carroll, Jo Daviess, Lee, Ogle), 2 (Cook, DeKalb, Kane, Lake, LaSalle, McHenry, Will), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria), 4 (Cass, Champaign, Coles, Macon, Menard, Moultrie, Vermilion), 5 (Clark, Crawford, Franklin, Jefferson, Randolph, St. Clair, Shelby), 6 (Alexander, Gallatin, Jackson, Johnson, Pope, Saline, Union).

Ptilium

crista-castrensis (Hedw.) DeNot. 3 (Fulton), 4 (Menard).

Pylaisiella

intricata (Hedw.) Grout. 2 (Cook, McHenry, Will), 3 (Fulton, Henderson, Peoria), 4 (Champaign, Menard).

polyantha (Hedw.) Grout. 2 (Fulton, Henderson), 4 (Menard).

selwynii (Kindb.) Crum, Steere, & Anderson. 1 (Jo Daviess, Ogle), 2 (DeKalb), 3 (Peoria), 4 (Champaign, Menard), 5 (Franklin, Shelby), 6 (Alexander, Union).

Taxiphyllum

deplanatum (Bruch & Schimp. *ex* Sull.) Fleisch. 1 (Carroll, Ogle, Winnebago), 2 (Cook), 3 (Fulton, Hancock, Peoria), 4 (Coles, Menard, Tazewell), 5 (Clark, Shelby).

taxirameum (Mitt.) Fleisch. 2 (DeKalb, LaSalle), 3 (Fulton, Hancock), 5 (Clark), 6 (Gallatin, Jackson, Union).

LESKEACEAE

Leskea

australis Sharp. 1 (Jo Daviess).

gracilescens Hedw. 1 (Jo Daviess, Ogle), 2 (Cook, DeKalb, Grundy, Lake, LaSalle, Will), 3 (Adams, Hancock, Henderson, McDonough, Peoria, Pike), 4 (Cass, Macon, Mason, Piatt, Vermilion), 5 (Franklin, Jefferson, Richland, Washington), 6 (Gallatin, Hardin, Jackson, Johnson, Pulaski, Saline, Union, Williamson).

nervosa (Brid.) Loeske. 2 (LaSalle), 4 (Macon).

obscura Hedw. 1 (Ogle, Winnebago), 2 (Cook, DeKalb, DuPage, Kane, Lake), 3 (Adams, Fulton, Henderson, Peoria), 4 (Champaign, Coles, Menard, Vermilion), 5 (Clark, Fayette, Franklin, Jefferson, Shelby), 6 (Hardin, Jackson, Johnson, Pulaski, Saline).

polycarpa Hedw. 1 (Carroll, Jo Daviess, Ogle, Stark), 2 (Cook, Will), 3 (Adams, Fulton, Hancock, Henderson, Peoria), 4 (Champaign, Coles, Macon, Menard, Moultrie), 5 (Clark, Crawford), 6 (Johnson, Pope, Saline, Union).

Lindbergia

brachyptera (Mitt.) Lindb. 1 (Carroll, Jo Daviess), 2 (Cook, Lake), 3 (Fulton), 4 (Cass, Coles, Menard), 5 (Clark).

Pterigynandrum

filiforme Hedw. 4 (Menard).

LEUCOBRYACEAE

Leucobryum

albidum (Brid. *ex* P. -Beauv.) Lindb. 2 (Cook), 3 (Fulton), 6 (Gallatin, Jackson, Johnson, Pope, Williamson).

glaucum (Hedw.) Angstr. ex Fr. 1 (Ogle, Winnebago), 2 (Cook, Lake, LaSalle), 3 (Adams, Fulton, Hancock, McDonough), 4 (Coles, Macon, Menard, Moultrie), 5 (Clark, Randolph), 6 (Gallatin, Hardin, Jackson, Johnson, Massac, Pope, Saline, Union, Williamson).

LEUCODONTACEAE

Leucodon

brachypus Brid. var. *brachypus*. 1 (Ogle).

var. *andrewsianus* Crum & Anderson. 1 (Ogle), 4 (Coles), 5 (Clark).

julaceus (Hedw.) Sull. 2 (Cook), 3 (Fulton, Peoria), 4 (Champaign, Coles, Menard, Vermilion), 5 (Clark, Franklin, Jefferson, Marion, Shelby), 6 (Gallatin, Jackson, Johnson, Pope, Pulaski, Saline, Union).

MEESIACEAE

Meesia

longiseta Hedw. 1 (Lake, McHenry).

MNIACEAE

Mnium

affine Bland *ex* Funck var. *ciliare* C.M. 1 (Jo Daviess, Rock Island), 3 (Adams, Hancock, McDonough), 5 (Randolph), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Pope, Union).

cuspidatum Hedw. 1 (Carroll, Henry, Jo Daviess, Ogle, Rock Island, Winnebago), 2 (Cook, DeKalb, DuPage, Grundy, Kane, Kankakee, Kendall, Lake, LaSalle, McHenry, Will), 3 (Adams, Calhoun, Fulton, Hancock, Henderson, McDonough, Mercer, Peoria), 4 (Cass, Coles, DeWitt, Macon, Mason, Menard, Moultrie, Tazewell, Vermilion), 5 (Clark, Crawford, Effingham, Franklin, Jasper, Jefferson, Randolph, Shelby), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Saline, Union).

drummondii Bruch & Schimp. 1 (Carroll).

hornum Hedw. 1 (Ogle).

marginatum (With.) Brid. *ex* P. -Beauv. 1 (Carroll, Jo Daviess), 2 (Kane, Lake), 4 (Coles, Menard), 5 (Clark), 6 (Jackson, Union).

medium B.S.G. 2 (Lake, LaSalle), 3 (McDonough), 4 (Moultrie).

punctatum Hedw. var. *punctatum* 1 (Carroll, Jo Daviess), 2 (LaSalle), 4 (Coles, Menard, Moultrie), 5 (Clark), 6 (Gallatin, Jackson, Johnson, Union).

var. *elatum* Schimp. 6 (Johnson).

rostratum Schrad. 1 (Ogle, Rock Island), 2 (Lake), 3 (Peoria), 4 (Champaign, Coles, Moultrie), 5 (Lawrence), 6 (Gallatin, Johnson, Saline).

spinulosum B.S.G. 1 (Jo Daviess, Ogle), 2 (LaSalle), 5 (Clark).

stellare Hedw. 1 (Carroll), 4 (Menard), 6 (Jackson, Williamson).

thomsonii Schimp. 2 (LaSalle), 3 (Hancock), 6 (Johnson).

NECKERACEAE

Neckera

pennata Hedw. 3 (Fulton).

Thamnobryum

alleghaniense (C. Muell.) Nieuwl. 3 (Fulton), 6 (Jackson, Johnson, Pope, Saline).

ORTHOTRICHACEAE

Drummondia

prorepens (Hedw.) Brid. 2 (Cook), 3 (Fulton, Peoria), 4 (Coles, Menard, Vermilion), 5 (Clark, Jasper, Marion), 6 (Gallatin, Hardin, Jackson, Johnson, Union).

Orthotrichum

anomalum Hedw. 2 (Will), 3 (Fulton), 4 (Menard).

ohioense Sull. & Lesq. *in* Aust. 1 (Rock Island), 3 (Fulton, McDonough), 4 (Coles), 5 (Crawford, Shelby).

pumilum Sw. 1 (Jo Daviess), 2 (Cook, DeKalb, LaSalle), 4 (Coles, Moultrie, Piatt), 5 (Clark).

pusillum Mitt. 2 (DeKalb), 4 (Cass), 5 (Jefferson, Shelby), 6 (Alexander, Jackson, Johnson, Pope, Union, Williamson).

stellatum Brid. 1 (Carroll, Winnebago), 3 (Hancock).

strangulatum P. -Beauv. var. *strangulatum* 1 (Carroll, Lee, Rock Island, Stark), 2 (Cook, LaSalle, McHenry, Will), 3 (Fulton, Hancock, Peoria), 4 (Coles, Menard, Moultrie), 5 (Clark, Marion), 6 (Union).

Ulota

crispa (Hedw.) Brid. 2 (Cook), 3 (Fulton), 4 (Menard), 5 (Shelby).

PLAGIOTHECIACEAE

Plagiothecium

cavifolium (Bird.) Iwats. 2 (Cook, Lake, LaSalle), 3 (Fulton, Hancock, Peoria), 4 (Menard), 5 (Clark, Randolph), 6 (Gallatin, Jackson, Johnson, Union, Williamson).

denticulatum (Hedw.) B.S.G. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook), 4 (Vermilion), 5 (Clark, Shelby), 6 (Jackson).

POLYTRICHACEAE

Atrichum

altecristatum (Ren. & Card.) Irel. 3 (Hancock).

angustatum (Brid.) B.S.G. 1 (Carroll, Jo Daviess, Ogle, Rock Island, Winnebago), 2 (Cook, DeKalb, Grundy, Kane, Kankakee, Lake, LaSalle, McHenry), 3 (Adams, Calhoun, Fulton, Hancock, Henderson, McDonough, McHenry), 4 (Cass, Champaign, Coles, Macon, Mason, Menard, Piatt, Vermilion), 5 (Clark, Crawford, Franklin, Marion, Monroe, Randolph, Shelby, Wabash, Washington), 6 (Gallatin, Jackson, Johnson, Pope, Saline, Union, Williamson).

oerstedianum (C. Muell.) Mitt. 3 (Hancock).

tenellum (Roehl.) B.S.G. 3 (Hancock).

undulatum (Hedw.) P. -Beauv. var. *undulatum*. 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, DeKalb, Kankakee, Lake, Will), 3 (Fulton, Hancock, Henderson, Peoria), 4 (Cass, Champaign, Macon, Menard, Moultrie, Vermilion), 5 (Clark, Crawford, Franklin, Shelby), 6 (Alexander, Gallatin, Jackson, Johnson, Pope, Saline, Union, Williamson).

var. *minus* (Hedw.) Par. 1 (Ogle), 2 (LaSalle), 3 (Hancock), 4 (Piatt).

Pogonatum

brachyphyllum (Michx.) P. -Beauv. 3 (Hancock), 6 (Jackson, Johnson, Pope).

pensilvanicum (Hedw.) Par. 2 (LaSalle), 3 (Fulton, Hancock, Peoria), 4 (Cass, Coles, Menard), 5 (Clark, Shelby), 6 (Jackson, Pope).

Polytrichum

commune Hedw. var. *commune*. 1 (Carroll, Jo Daviess, Ogle, Lee, Rock Island, Winnebago), 2 (Cook, Grundy, Lake, McHenry, Will), 3 (Adams, Brown, Hancock), 4 (Cass, Coles, Mason, Menard, Vermilion), 5 (Clark, Effingham, Lawrence, Randolph, St. Clair), 6 (Gallatin, Jackson, Johnson, Pope, Union).

var. *perigonale* (Michx.) B.S.G. 1 (Winnebago).

formosum Hedw. 4 (Menard), 6 (Union).

juniperinum Hedw. var. *juniperinum* 1 (Carroll, Ogle, Whiteside), 2 (Cook, Kane, Lake, LaSalle), 3 (Fulton, Hancock, Henderson, McDonough, Peoria), 4 (Coles, Mason, Menard, Moultrie, Vermilion), 5 (Clark, Randolph), 6 (Jackson, Johnson, Pope, Saline, Union, Williamson).

var. *gracilis* Wahlenb. 2 (Lake).

longisetum Brid. 2 (Lake), 4 (Menard).

ohioense Ren. & Card. 1 (Ogle), 2 (Cook, Kankakee, LaSalle), 4 (Coles, Menard), 5 (Clark, Randolph), 6 (Gallatin, Hardin, Jackson, Johnson, Massac, Pope, Saline, Union, Williamson).

piliferum Hedw. 1 (Ogle), 5 (Clark).

strictum Brid. 2 (Lake).

POTTIACEAE

Acaulon

muticum (Hedw.) C. Muell, var. *rufescens* (Jaeg.) Crum. 4 (Menard, Sangamon), 5 (Jackson).
schimperianum (Sull.) Sull. *ex* Sull. & Lesq. 4 (Menard).
triquetrum (Spruce) C. Muell. 4 (Menard).

Aloina

aloides (Koch *ex* Schultz) Kindb. var. *ambigua* (B.S.G.) Craig. 4 (Menard).
rigida (Hedw.) Limpr. 4 (Menard).

Barbula

cancellata C. Muell. 3 (Hancock), 6 (Johnson, Williamson).
convoluta Hedw. 2 (DeKalb), 3 (Hancock).
fallax Hedw. 1 (Carroll, Jo Daviess, Whiteside), 2 (Cook, Lake, LaSalle), 3 (Adams, Fulton, Hancock, Henderson, Peoria), 4 (Coles, Menard, Vermilion), 5 (Clark).
unguiculata Hedw. 1 (Carroll, Jo Daviess, Ogle, Whiteside), 2 (Cook, DeKalb, DuPage, Lake, LaSalle, McHenry, Will), 3 (Adams, Fulton, Hancock, Henderson, McDonough), 4 (Cass, Champaign, Menard, Moultrie, Piatt), 5 (Clark, Cumberland, Hamilton, Lawrence, Randolph, Shelby), 6 (Williamson).
vinealis Brid. 4 (Menard).

Bryoerythrophyllum

recurvirostrum (Hedw.) Chen. 1 (Ogle, Jo Daviess), 2 (Cook, LaSalle), 3 (Fulton, Hancock), 4 (Coles, Menard), 5 (Clark, Hamilton), 6 (Hardin).

Desmatodon

obtusifolius (Schwaegr.) Schimp. 1 (Ogle), 2 (Cook, Grundy, LaSalle), 3 (Adams, Fulton, Hancock, Peoria, Schuyler), 4 (Coles, Mason), 5 (Clark, Randolph), 6 (Jackson).
plinthobius Sull. & Lesq. *ex* Sull. 3 (Adams, Hancock), 5 (Jasper, St. Clair), 6 (Hardin).
porteri James *ex* Aust. 2 (Kankakee, Will), 3 (Fulton, Peoria), 4 (Coles), 5 (Clark), 6 (Hardin, Johnson).
randii (Kenn.) Laz. 2 (Cook).

Didymodon

rigidulus Hedw. No locality given (Wolfe &Hall, 1878).
tophaceus (Brid.) Lisa. 2 (Cook), 3 (Hancock).

Eucladium

verticillatum (Brid.) B.S.G. 6 (Hardin).

Gymnostomum

aeruginosum Sm. 1 (Jo Daviess), 2 (Cook, LaSalle), 3 (Adams, Hancock, Peoria), 5 (Jackson).
recurvirostrum Hedw. var. *recurvirostrum*. 1 (Jo Daviess, Ogle), 2 (Cook, Kane, Kankakee, LaSalle), 3 (Adams, Hancock, McDonough).
var. *latifolium* (Zett.) Flow *ex* Crum. 1 (Jo Daviess), 3 (Peoria).

Hyophila

involuta (Hook.) Jaegr. & Sauerb. 2 (LaSalle), 3 (Adams, Hancock), 6 (Jackson).

Phascum

cuspidatum Hedw. 3 (Fulton, Hancock, Peoria), 4 (Menard, Piatt, Sangamon).
floerkeanum Web. & Mohr. No locality given (Hauge, 1930).

Pottia
truncata (Hedw.) Fuernr. *ex* B.S.G. 4 (Macon).

Pterigoneurum
subsessile (Brid.) Jur. var. *subsessile.* 4 (Menard).

Scopelophila
ligulata (Spruce) Spruce. 2 (LaSalle), 6 (Johnson).

Tortella
humilis (Hedw.) Jenn. 1 (Carroll), 2 (Cook, Lake, LaSalle), 3 (Fulton, Hancock, Peoria), 4 (Coles, Menard, Moultrie), 5 (Clark, Randolph), 6 (Hardin, Jackson, Pope, Union, Williamson).

Tortula
mucronifolia Schwaegr. 2 (Lake), 4 (Coles, Menard), 5 (Clark).
pagorum (Milde) DeNot. 4 (Menard), 5 (Jefferson, Randolph), 6 (Gallatin).
papillosa Wils. *ex* Spruce. 4 (Menard).
ruralis (Hedw.) Gaertn., Meyer, & Schreb. 1 (Ogle).
subulata Hedw. No locality given (Wolf & Hall, 1878).

Weissia
controversa Hedw. var. *controversa.* 1 (Jo Daviess, Ogle, Rock Island, Whiteside), 2 (Cook, Grundy, Lake, LaSalle, McHenry), 3 (Adams, Calhoun, Fulton, Hancock, Jersey, McDonough), 4 (Cass, Champaign, Coles, Macon, Menard, Moultrie, Sangamon), 5 (Clark, Effingham, Franklin, Randolph, St. Clair), 6 (Gallatin, Hardin, Jackson, Johnson, Pope, Union).
var. *wolfii* (Lesq. & James) Crum, Steere, & Anderson. 3 (Fulton).
muhlenbergiana (Sw.) Reese & Lemon. 4 (Piatt).

PTYCHOMITRIACEAE

Ptychomitrium
drummondii (Wils.) Sull. 5 (Franklin), 6 (Johnson, Pulaski).
incurvum (Schwaegr.) Sull. 1 (Ogle), 6 (Jackson, Johnson, Pope, Union, Williamson).

RHYTIDIACEAE

Rhytidium
rugosum (Hedw.) Kindb. 1 (Carroll).

Rhytidiadelphus
triquetrus (Hedw.) Warnst. 1 (Ogle), 2 (Cook, DeKalb, Lake), 3 (Fulton), 4 (Menard).

SEMATOPHYLLACEAE

Brotherella
recurvans (Michx.) Fleisch. 3 (Fulton), 4 (Coles), 5 (Clark, Shelby).
tenuirostris (Bruch & Schimp. *ex* Sull.) Broth. 1 (Ogle), 3 (Fulton), 4 (Menard), 5 (Pope, Union, Williamson).

Sematophyllum

adnatum (Michx.) Britt. 2 (Cook, Kankakee, Will), 3 (Fulton, Hancock, Peoria), 4 (Coles, Menard), 6 (Pope, Union).

demissum (Wils.) Mitt. 2 (LaSalle), 4 (Coles), 5 (Clark), 6 (Gallatin, Jackson, Johnson, Pope, Williamson).

SPHAGNACEAE

Sphagnum

capillaceum (Weiss) Schrank var. *capillaceum.* 2 (Cook, Kane, Lake, Will), 5 (Clark, Randolph), 6 (Pope).

var. *tenellum* (Schimp.) Andr. 2 (Lake).

centrale C. Jens. 1 (Winnebago), 2 (Lake).

compactum Lam. & DC. 2 (Cook, Grundy, Will), 5 (Randolph), 6 (Jackson, Pope).

cuspidatum Ehrh. *ex* Hoffm. var. *cuspidatum* 2 (Cook, Kane, Lake), 6 (Jackson, Williamson).

fimbriatum Wils. *ex* J. Hook. 3 (McDonough).

fuscum (Schimp.) Klinggr. 2 (Lake).

girgensohnii Russ. 2 (LaSalle, McHenry).

imbricatum Hornsch. *ex* Russ. 2 (Kane), 3 (Fulton), 6 (Massac, Pope).

magellanicum Brid. 2 (Kane, Lake, McHenry).

palustre L. 2 (Kendall, Lake, LaSalle), 5 (Clark), 6 (Williamson).

papillosum Lindb. 1 (Winnebago), 2 (Kane).

recurvum P. -Beauv. var. *recurvum* 2 (Cook, Lake, McHenry), 6 (Johnson).

var. *tenue* Klinggr. 2 (Lake, McHenry).

squarrosum Crome. 2 (Kankakee, Lake), 4 (Clark).

subsecundum Nees *ex* Sturm. 1 (Ogle, Winnebago), 2 (Lake, McHenry), 5 (Clark), 6 (Johnson, Pope).

var. *rufescens* (Nees, Hornsch. & Sturm) Hueb. 2 (Grundy).

tenerum Sull. & Lesq. 5 (Randolph), 6 (Pope).

teres (Schimp.) Angstr. *ex* C. Hartm. 1 (Ogle), 2 (Lake), 3 (McDonough), 5 (Clark).

warnstorfii Russ. 2 (Lake).

TETRAPHIDACEAE

Tetraphis

pellucida Hedw. 1 (Ogle), 2 (Cook, Kane, Lake, LaSalle), 4 (Coles, Menard), 5 (Clark, Franklin, Shelby), 6 (Gallatin, Jackson, Johnson, Pope, Union).

THELIACEAE

Myurella

sibirica (C. Muell.) Reim. var. *sibirica*. 1 (Jo Daviess), 2 (LaSalle).

Thelia

asprella Sull. 1 (Jo Daviess, Lee), 2 (Cook, DeKalb, Lake), 3 (Hancock, Henderson, Peoria), 4 (Coles, Mason, Moultrie), 5 (Clark).

hirtella (Hedw.) Sull. 1 (Carroll, Rock Island), 2 (McHenry), 3 (Fulton, Peoria), 4 (Menard), 6 (Johnson, Pope).

lescurii Sull. 1 (Ogle), 2 (Cook), 3 (Adams, Fulton, Hancock), 6 (Jackson, Union).

THUIDIACEAE

Anomodon

attenuatus (Hedw.) Hueb. 1 (Carroll, Jo Daviess, Ogle, Rock Island), 2 (Cook, DeKalb, Kane, Lake, LaSalle, McHenry, Will), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria), 4 (Cass, Champaign, Coles, Menard, Moultrie), 5 (Clark, Crawford, Franklin, Marion, Monroe, Randolph, Shelby), 6 (Alexander, Gallatin, Hardin, Jackson, Johnson, Pope, Saline, Union).

minor (Hedw.) Fuernr. 1 (Carroll, Jo Daviess, Ogle, Rock Island), 2 (Cook, DeKalb, DuPage, Kane, McHenry, Will), 3 (Fulton, Hancock, McDonough, Peoria), 4 (Champaign, Coles, Menard, Vermilion), 5 (Clark, Franklin, Marion, Monroe, Randolph, Shelby), 6 (Johnson, Union).

rostratus (Hedw.) Schimp. 1 (Carroll, Jo Daviess, Ogle, Whiteside), 2 (Cook, DuPage, Lake, LaSalle, Will), 3 (Adams, Brown, Fulton, Hancock, McDonough, Peoria), 4 (Cass, Champaign, Coles, Macon, Menard, Vermilion), 5 (Clark, Crawford, Effingham, Franklin, Randolph, Shelby), 6 (Gallatin, Jackson, Johnson, Pope, Union).

rugelli (C. Muell.) Keissl. 1 (Ogle), 6 (Johnson, Pope, Saline).

viticulosus (Hedw.) Hook. & Tayl. 1 (Carroll, Jo Daviess), 2 (McHenry), 6 (Johnson).

Haplocladium

microphyllum (Hedw.) Broth. 1 (Ogle), 2 (Cook, Kane, Lake, McHenry), 3 (Fulton, Peoria), 4 (Cass, Macon, Menard), 5 (Crawford, Jefferson), 6 (Alexander, Jackson, Pulaski).

virginianum (Brid.) Broth. 1 (Jo Daviess, Ogle), 2 (DeKalb, Kane), 3 (Henderson, McDonough), 4 (Cass, Champaign, Coles, Mason, Menard, Tazewell), 5 (Clark, Franklin, Randolph, Wayne), 6 (Jackson, Johnson, Union).

Haplohymenium

triste (Ces. *ex* DeNot) Kindb. 3 (Fulton, Peoria), 4 (Menard).

Helodium

blandowii (Web. & Mohr.) Warnst. 1 (Winnebago).

paludosum (Sull.) Aust. 2 (Lake), 4 (Menard).

Heterocladium

dimorphum (Brid.) B.S.G. 3 (Fulton).

Thuidium

abietinum (Hedw.) B.S.G. 5 (Clark).

delicatulum (Hedw.) B.S.G. var. *delicatulum* 1 (Carroll, Jo Daviess, Ogle), 2 (Cook, DeKalb, Lake, Will), 3 (Adams, Fulton, Hancock, Henderson, McDonough, Peoria), 4 (Coles, Macon, Menard, Moultrie), 5 (Clark, Crawford, Marion, Randolph, Shelby), 6 (Gallatin, Jackson, Pope, Saline, Union, Williamson).

var. *radicans* (Kindb.) Crum, Steere, & Anderson. 6 (Gallatin, Pope, Union).

minutulum (Hedw.) B.S.G. 3 (Fulton, Henderson, Peoria), 4 (Menard), 6 (Union).

pygmaeum B.S.G. 1 (Carroll, Jo Daviess), 4 (Macon, Menard), 5 (Clark), 6 (Saline).

recognitum (Hedw.) Lindb. 1 (Jo Daviess, Ogle), 2 (Lake, LaSalle, McHenry), 3 (McDonough, Peoria), 4 (Cass, Champaign), 5 (Clark, Randolph, Shelby), 6 (Gallatin, Jackson, Johnson, Pope, Union, Williamson).

scitum (P. -Beauv.) Aust. 3 (Fulton), 4 (Menard).

TIMMIACEAE

Timmia

megapolitana Hedw. 1 (Carroll, Jo Daviess, Ogle, Winnebago), 2 (Cook, Lake, LaSalle,), 3 (Adams, Fulton, Henderson, Peoria), 4 (Cass, Menard), 5 (Clark, Hamilton), 6 (Union).

SUMMARY

A review of the distribution of the mosses of Illinois shows that 342 taxa have been reported in the literature or are present in herbaria. The taxa are distributed in 42 families, 321 species, and 20 varieties. The county with the most taxa reported is Menard (151). Other counties with a relative large number of taxa include Fulton (130), Cook (123), Clark (120) and Jackson (113). Twelve counties appear to have no taxa recorded from them. As is indicated by Figure 2, a number of counties need collecting to either verify their paucity of taxa or to record more accurately the taxa present.

We certainly wish to acknowledge the recent bryological work done in Illinois. In addition to our own work, the works of Arzeni, Stotler, Snider, O'Flaherty, Zales, and Zehr and their students should be mentioned.

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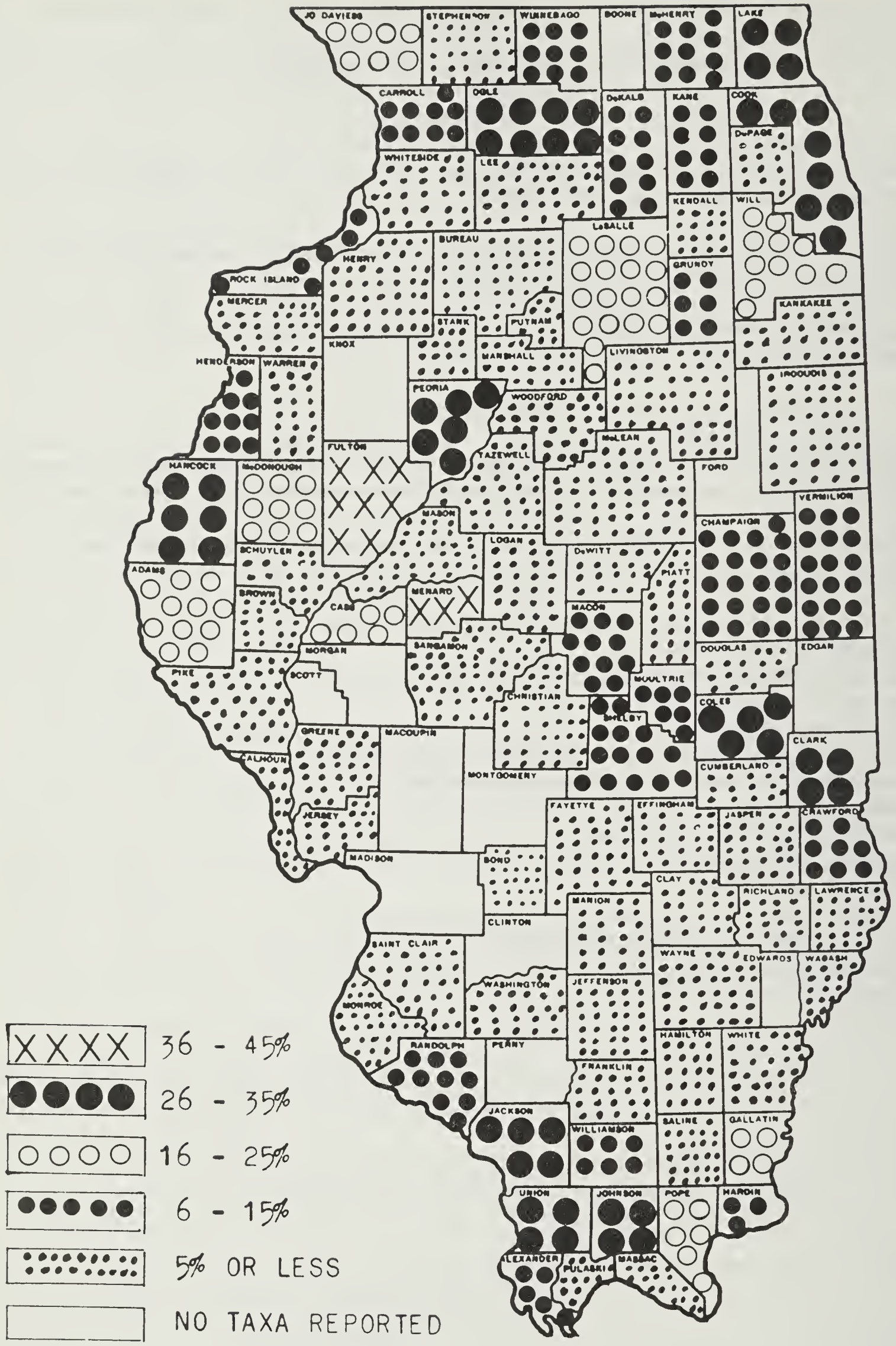
Figure 1. Distribution areas used in reporting county records of mosses superimposed on the natural divisions of Illinois (produced for the Illinois Nature Preserves Commission by John Schwegman).

Figure 2. Number of taxa present in each county as a percentage of total taxa reported for state (341).

1. Wisconsin Driftless Division
2. Rock River Hill Country Division
3. Northeastern Morainal Division
4. Grand Prairie Division
5. Upper Mississippi River and Illinois River Bottomlands Division
6. Illinois River and Mississippi River Sand Area Division
7. Western Forest-Prairie Division
8. Middle Mississippi Border Division
9. Southern Till Plain Division
10. Wabash Border Division
11. Ozark Division
12. Lower Mississippi River Bottomlands Division
13. Shawnee Hills Division
14. Coastal Plain Division


JO DAVIESS
STEPHENSON
WINNEBAGO
BOONE
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DuPAGE
WHITESIDE
LEE
KENDALL
WILL
LaSALLE
BUREAU
GRUNDY
HENRY
ROCK ISLAND
MERCER
KANKAKEE
STARK
PUTNAM
KNOX
MARSHALL
LIVINGSTON
HENDERSON
WARREN
IROQUOIS
PEORIA
WOODFORD
McLEAN
FULTON
TAZEWELL
FORD
HANCOCK
McDONOUGH
VERMILION
MASON
CHAMPAIGN
SCHUYLER
LOGAN
DeWITT
ADAMS
PIATT
BROWN
MENARD
CASS
MACON
DOUGLAS
EDGAR
MORGAN
SANGAMON
PIKE
SCOTT
MOULTRIE
CHRISTIAN
COLES
SHELBY
GREENE
MACOUPIN
CLARK
CALHOUN
CUMBERLAND
MONTGOMERY
FAYETTE
EFFINGHAM
JASPER
CRAWFORD
JERSEY
MADISON
BOND
CLAY
MARION
RICHLAND
LAWRENCE
CLINTON
SAINT CLAIR
WAYNE
EDWARDS
WABASH
WASHINGTON
JEFFERSON
MONROE
HAMILTON
WHITE
RANDOLPH
PERRY
FRANKLIN
JACKSON
SALINE
GALLATIN
WILLIAMSON
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC
XXXX 36 - 45%
26 - 35%
16 - 25%
6 - 15%
5% OR LESS
NO TAXA REPORTED

1 WISCONSIN DRIFTLESS DIVISION

2 ROCK RIVER HILL COUNTRY DIVISION

3 NORTHEASTERN MORAINAL DIVISION

4 GRAND PRAIRIE DIVISION

5 UPPER MISSISSIPPI RIVER AND ILLINOIS RIVER BOTTOMLANDS DIVISION

6 ILLINOIS RIVER AND MISSISSIPPI RIVER SAND AREA DIVISION

7 WESTERN FOREST-PRAIRIE DIVISION

8 MIDDLE MISSISSIPPI BORDER DIVISION

9 SOUTHERN TILL PLAIN DIVISION

10 WABASH BORDER DIVISION

11 OZARK DIVISION

12 LOWER MISSISSIPPI RIVER BOTTOMLANDS DIVISION

13 SHAWNEE HILLS DIVISION

14 COASTAL PLAIN DIVISION

ADDITIONS TO THE VASCULAR FLORA OF WEST CENTRAL ILLINOIS

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ABSTRACT

One hundred forty-one additional county distribution records are reported from west-central Illinois counties.

One hundred forty-one additional vascular plant distribution records for west-central Illinois counties were compiled from the spring of 1978 through the spring of 1979. Of these 141 records, 92 are native plants and 49 are alien as based on Myers (1972). Distribution status of the plants was determined from the work of Mohlenbrock and Ladd (1978) and nomenclature follows Mohlenbrock (1975) except where noted. Voucher specimens of *Potamogeton* and *Najas* are deposited in the WIU Kibbe Life Science Station Herbarium (WARK), with all remaining voucher specimens deposited in the R.M. Myers Herbarium of Western Illinois University (MWI).

Two plants on the following list of records merit comment on their distribution. An approximately 10 square meter colony of *Arundinaria gigantea* (Walt.) Chapm. was located in a sandy stream bed and adjacent bank in northwestern Greene County. This station extends the northern range of this plant in Illinois by approximately 50 miles. Also interesting were two collections of *Crepis tectorum* L. in McDonough County. This plant, an alien from Europe, was collected from two widely separated locations (15 miles apart), both along highways. This species has been previously reported only from four northeastern Illinois counties. The McDonough County collections represent a significant westward extension of the Illinois range of this plant. A single Missouri collection of this species has also been reported from a St. Louis County railroad yard (Steyermark, 1963).

Also included in this report are the following notes on four color forms collected in west central Illinois. *Dodecatheon meadia* L. f. *album* Macbr. was collected (Coll. No. 1048, 1050) from Schuyler County, Illinois. The colony of plants consisted of numerous purple flowered plants (Coll. No. 1047, 1049) interspersed occasionally by plants of forma *album*. Several specimens (Coll. No. 1083, 1084) of *Cassia fasciculata* Michx. with conspicuously pale cream colored flowers were collected from a colony of normal appearing golden-flowered *C. fasciculata* along a roadside in McDonough County. Steyermark (1963) determines such light colored specimens to be *C. fasciculata* Michx. var. *fasciculata* f. *Jenseni* Palmer & Steyerm. In Missouri this form is known only from two east-central counties. *Phalaris arundinacea* L. f. *picta* (L.) Asch. & Graebn. (Coll. No. 1068-1072) was collected from a McDonough County roadside ditch growing in a large colony with typical *P. arundinacea*. The white striped forma *picta* was noted to flower approximately five days later than the solid green leaved *P. arundinacea*. *Trifolium pratense* L. f. *leucochraceum* Aschers. & Prantl was collected from two locations in McDonough County (Coll. No. 1063-1065). Plants with pure white flowers grew among typical colored stands of *T. pratense*. The distribution of forma *leucochraceum* in McDonough County appears to be occasional based on these collections and observations during Spring 1979.

The following list of plant distribution records appears in the sequence presented in Mohlenbrock and Ladd (1978). Included for each plant is the county from which it was collected, the habitat and the collection number(s). Collections were made by the authors unless otherwise noted.

Abutilon theophrasti: WARREN, by railroad. No. 767.
Acorus calamus: WARREN, wet ground. No. 939, 940.
Agastache nepetoides: WARREN, by railroad. No. 766.
Ailanthus altissima: WARREN, by railroad. No. 820.
Alopecurus carolinianus: SCHUYLER, mudflat. No. 1086.
Alopecurus pratensis: SCOTT, cemetery. No. 1097.
Amaranthus retroflexus: WARREN, waste ground. No. 963.
Amelanchier arborea: WARREN, limestone bluff. No. 855, 856.
Antennaria neglecta: BROWN, cemetery. No. 1109. SCHUYLER, cemetery. No. 1024, 1025. WARREN, cemetery. No. 829, 830.
Antennaria plantaginifolia: WARREN, cemetery. No. 828.
Aquilegia canadensis: SCHUYLER, rocky wooded hillside. No. 1038.
Arabis shortii: WARREN, floodplain. No. 780, 781.
Arenaria serpyllifolia: SCHUYLER, wooded pasture. No. 1060, 1061.
Artemisia ludoviciana var. *gnaphalodes*: WARREN, cemetery. No. 958.
Arundinaria gigantea: GREENE, damp stream bed. No. 1103, 1104. Also D. Hess, s.n.
Asarum canadense var. *reflexum*: WARREN, floodplain. No. 859.
Asparagus officinalis: WARREN, roadside. No. 948.
Aster azureus: WARREN, railroad prairie. No. 752, 753.
Aster ericoides var. *prostratus*: WARREN, by railroad. No. 762.
Aster prealtus: WARREN, by railroad. No. 750, 751.
Barbarea vulgaris var. *arcuata*: SCOTT, old field. No. 1098-1100.
Bidens cernua: WARREN, wet ground. No. 860.
Blephilia hirsuta: SCHUYLER, moist wooded slope. No. 1004, 1005.
Brassica nigra: WARREN, roadside. No. 747.
Brickellia eupatorioides: WARREN, cemetery. No. 965, 957.
Bromus pubescens: WARREN, damp woods. No. 887.
Camelina microcarpa: WARREN, by railroad. No. 819.
Cardamine bulbosa: WARREN, swamp. No. 910.
Cardamine parviflora var. *arenicola*: SCHUYLER, wet ground. No. 1023. SCOTT, old field. No. 1092, 1093. WARREN, old field. No. 831.
Carex lanuginosa: WARREN, swamp. No. 980.
Carex pensylvanica: GREENE, wooded slope. No. 1102. WARREN, railroad swamp. No. 825.
Carex stipata: SCHUYLER, railroad ditch. No. 1090. WARREN, damp woods. No. 981.
Carex substricta: WARREN, roadside ditch. No. 851.
Catalpa speciosa: SCHUYLER, roadside. No. 1058. WARREN, roadside. No. 955.
Cercis canadensis: WARREN, floodplain. No. 854.
Chaerophyllum procumbens: SCHUYLER, floodplain. No. 1033, 1034. WARREN, floodplain. No. 848.
Chrysanthemum leucanthemum: SCHUYLER, roadside. No. 1011.
Cirsium discolor: WARREN, railroad prairie. No. 760.
Comandra richardsiana: WARREN, cemetery. No. 775.
Conium maculatum: WARREN, ditch. No. 812.
Convolvulus arvenis: WARREN, by railroad. No. 920.
Coreopsis grandiflora: CASS, roadside. No. 1106.
Coreopsis palmata: WARREN, railroad prairie. No. 759.
Crepis tectorum: MCDONOUGH, roadside. No. 1074-1077.
Datura stramonium: WARREN, waste ground. No. 967.
Descurainia pinnata var. *brachycarpa*: WARREN, by railroad. No. 796.
Desmodium canadense: WARREN, cemetery. No. 745, 746.
Dodecatheon meadia: SCHUYLER, rocky wooded hillside. No. 1047-1050.
Eleocharis erythropoda: WARREN, swamp. No. 908, 909.

Erigeron strigosus: WARREN, railroad prairie. No. 899.
Euphorbia cyparissias: WARREN, cemetery. No. 870.
Festuca obtusa: WARREN, damp woods. No. 952.
Fragaria virginiana: WARREN, cemetery. No. 838, 839.
Geranium carolinianum: WARREN, by railroad. No. 919.
Glechoma hederacea: WARREN, floodplain. No. 853.
Glechoma hederacea var. *micrantha*: WARREN, floodplain. No. 852.
Gymnocladus dioica: SCHUYLER, moist wooded slope. No. 1014. WARREN, floodplain. No. 858.
Helianthus hirsutus: WARREN, railroad prairie. No. 743.
Helianthus rigidus: WARREN, railroad prairie. No. 744.
Hesperis matronalis: SCHUYLER, roadside. No. 1000.
Hordeum pusillum: WARREN, roadside. No. 742.
Houstonia minima: SCHUYLER, wooded pasture. No. 1059.
Hydrophyllum virginianum: WARREN, wooded floodplain. No. 782.
Iris germanica: WARREN, roadside. No. 805, 806.
Iris shrevei: WARREN, swamp. No. 911, 912.
Isopyrum biternatum: WARREN, wooded roadside. No. 834.
Juncus torreyi: WARREN, wet ground. No. 768.
Lepidium campestre: WARREN, by railroad. No. 792-794.
Lonicera x *bella*: WARREN, edge of woods. No. 769, 886.
Lychnis alba: WARREN, roadside. No. 893, 894.
Lysimachia nummularia: SCHUYLER, cemetery. No. 1052. SCOTT, cemetery. No. 1094-1096. WARREN, cemetery. No. 827.
Malus pumila: WARREN, by railroad. No. 867-869.
Malva neglecta: WARREN, waste ground. No. 960.
Matricaria matricarioides: WARREN, roadside. No. 813.
Mertensia virginica: BROWN, woods. No. 1107.
Muhlenbergia frondosa: WARREN, cemetery. No. 888.
Myosurus minimus: MORGAN, old field. No. 1101. SCHUYLER, corn field. No. 1022.
Najas minor: HANCOCK, submerged in Mississippi River. No. 1082.
Nasturtium officinale: WARREN, in stream. No. 770, 771.
Panicum oligosanthes: WARREN, cemetery. No. 808.
Parietaria pensylvanica: SCHUYLER, moist wooded slope. No. 1002.
Pedicularis canadensis: WARREN, cemetery. No. 776.
Phlox divaricata var. *laphamii*: WARREN, floodplain. No. 799-801.
Phlox maculata: CASS, swamp. No. 1105.
Poa annua: WARREN, yard. No. 850.
Polygonum aviculare: WARREN, roadside. No. 866.
Polygonum cuspidatum: MCDONOUGH, roadside dump. No. 1066, 1067.
Polygonum erectum: WARREN, roadside. No. 865.
Polygonum hydropiper: WARREN, waste ground. No. 965.
Polygonum persicaria: WARREN, waste ground. No. 966.
Populus deltoides: SCOTT, roadside. No. 1091. WARREN, roadside. No. 837.
Potamogeton crispus: LASALLE, in Illinois River. B. Thomas, s.n. MARSHALL, submerged. B. Thomas, s.n.
Prenanthes aspera: MASON, sand prairie. J. Ives, s.n.
Prunus americana: WARREN, roadside. No. 777
Prunus americana var. *lanata*: SCHUYLER, roadside. No. 1015.
Prunus hortulana: SCHUYLER, roadside. No. 1017.
Prunus persica: SCHUYLER, roadside. No. 1016.
Prunus virginiana: WARREN, edge of woods. No. 885.
Ranunculus fascicularis: WARREN, limestone bluff. No. 857.

Rhamnus cathartica: WARREN, railroad prairie. No. 758.
Ribes odoratum: WARREN, roadside. No. 842.
Robinia pseudoacacia: WARREN, low wet ground. No. 941, 942.
Salix humilis: WARREN, cemetery. No. 889, 890.
Salix humilis var. *microphylla*: WARREN, cemetery. No. 891, 892.
Salix interior: WARREN, wet ground. No. 934.
Salix rigida: SCHUYLER, floodplain. No. 1057.
Sanguinaria canadensis: WARREN, wooded roadside. No. 835.
Scrophularia lanceolata: WARREN, railroad prairie. No. 897.
Senecio pauperculus: WARREN, wet ground. No. 935.
Senecio vulgaris: MCDONOUGH, lawn. No. 1078, 1080.
Silene antirrhina: WARREN, railroad prairie. No. 896.
Sisyrinchium albidum: WARREN, cemetery. No. 809.
Sisyrinchium angustifolium: WARREN, damp woods. No. 816.
Sisyrinchium campestre: WARREN, by railroad. No. 882.
Solidago rigida: WARREN, railroad prairie. No. 755.
Tragopogon dubius: SCHUYLER, roadside. No. 1001.
Tragopogon pratensis: WARREN, roadside. No. 947.
Veronica polita: MCDONOUGH, lawn. No. 1081. Also D. Camp No. 509, D. Witt, s.n. and V. Kuhl, s.n.
Viburnum lentago: WARREN, edge of woods. No. 779.
Vicia dasycarpa: WARREN, railroad prairie. No. 902.
Viola missouriensis: WARREN, railroad ballast. No. 786.
Viola sagittata: BROWN, cemetery. No. 1108.
Woodsia obtusa: SCHUYLER, moist wooded slope. No. 1085.
Xanthoxylum americanum: SCHUYLER, edge of woods. No. 994. WARREN, damp woods. No. 785.
Zizia aurea: SCHUYLER, moist wooded hillside. No. 983. WARREN, railroad prairie. No. 903.

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INDICATED TRENDS OF MERCURY IN AQUATIC AND TERRESTRIAL FOOD CHAINS IN ILLINOIS

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ABSTRACT

Sources of mercury in the State of Illinois, including industrial, municipal, and institutional wastes, consumption of fossil fuels, and natural sources are examined. Historical records of the Illinois Environmental Protection Agency are reviewed for trends of mercury concentrations in Illinois' waters and sediments and for evidence of mercury accumulation in constituent organisms of terrestrial and aquatic food chains. There appears to be no evidence at this time of serious or widespread mercury contamination in Illinois.

INTRODUCTION

Mercury is ubiquitous. Compounds of mercury are found throughout the world in most rocks, soils, water, air, and in living organisms in low concentrations. A constant interchange takes place between these entities as a result of physical, chemical, and biological forces (see Figure 1). Most igneous rocks average about 100 ppb Hg (parts per billion of mercury), excluding those regions adjacent to ore deposits and mineralizations. (Fleisher, 1970). Sedimentary rocks generally have contents less than 200 ppb. The mercury content of soils averages about 100 ppb and varies within relatively narrow limits. As one would expect, mercury occurs in higher concentrations in many mineral deposits and in most fossil fuels.

Hem (1970) used a thermodynamic model to determine the theoretical mercury saturation level in water as approximately 25 ppb above pH levels of 5. However, such levels are seldom, if ever, encountered in natural waters because: mercury tends to be volatile resulting in loss at the water-air interface; most mercury species are much more soluble in organic solvents than in water resulting in uptake and concentration in aquatic organisms; and, mercury has a strong tendency to adsorb onto suspended matter which eventually settles to the bottom. Wershaw (1970) reported on surface water samples from 31 states in which 65 percent of the samples had a concentration level of less than 0.1 ppb, 15 percent had a level above 1.0 ppb, and, only 3 percent had a level above 5.0 ppb. From this

and other surveys, Wershaw concluded that the natural mercury content of unpolluted rivers in areas where mercury deposits are not known is less than 0.1 ppb. Stock and Cucuel (1934) reported an average of 0.2 ppb Hg in rain water and an oceanic concentration of 0.03 ppb Hg.

Mercury concentrations in the atmosphere are quite variable in space and time. McCarthy, et al. (1970) indicates that mercury is released to the atmosphere from surface rocks and soils as the barometric pressure drops with concentrations reaching a maximum as the rate of fall of barometric pressure is greatest. Diurnal variations were also noted with maximums observed at midday and minimums appearing at or near midnight. Rankama and Sahama (1950) reported that mercury in the atmosphere is removed by rain. This cleansing action was substantiated by McCarthy, et al. (1970) when the atmospheric concentration was measured at 20 ng/m^3 above the Ord Mine in Arizona on the day before a rainstorm but was undetectable several hours afterwards. They further observed background concentrations in the Southwestern United States ranging from 3 to 9 ng/m^3 whereas Williston (1968) found background concentrations of 0.6 to 0.7 ng/m^3 at a distance of 20 miles offshore in the Pacific Ocean. These findings suggest that the land surface is the primary natural contributor of mercury to the atmosphere.

Mercury is concentrated in living things by way of the food chain or by direct assimilation from the surrounding medium. Biomagnification within the food chain causes those organisms near the top to have the greatest concentration. Within any given organism the mercury is more highly concentrated in certain tissues such as the blood, hair, feathers, kidneys, liver, and brain. In man, mercury causes permanent damage to the central nervous system, and, in sufficient quantities can cause paralysis, coma, and death.

SOURCES IN ILLINOIS

Mercury is classed as a chalcophilic element; an element that occurs in concentration with sulfides. The most common mercury ores are cinnabar and metacinnabar — both sulfides of mercury. Although there are no known deposits of mercury ores in Illinois there are sources associated with other minerals such as galena (a lead sulfide) and with coal deposits where the mercury appears in conjunction with pyrite (also a sulfide). However, none of these are of commercial interest as a source of mercury, and, because of the relative insolubility of mercury sulfides (and other factors) these sources do not create a site-source of water pollution in Illinois. Consequently, the sources of concern to the environment in Illinois occur as a result of anthropomorphic activities such as manufacturing, mining, and consumption of mercury-bearing products produced in other states.

The flow of mercury into the waterways as a result of manufacturing processes and from consumption of mercury-bearing products is rather accurately indicated by the Illinois Environmental Protection Agency (IEPA) effluent sampling data. Cook and Rogers (1977) analyzed the IEPA sampling data for 13,663 samples from 1,683 stations taken from late 1971 to early 1977. The stations included effluents from municipal wastewater treatment plants, industrial plants, educational institutions, and nursing homes. During the study period the sampling rate for total mercury decreased from over 1,200 samples per quarter (year) to less than 200 samples per quarter as illustrated in Figure 2. This decrease in sampling rate was attributed to several factors including IEPA budget restrictions for this activity arising from the low number of observed violations of mercury effluent standards.

During this same time period, the mean mercury concentration in ppb decreased from approximately 0.4 ppb Hg to about 0.1 ppb Hg, with some rather large excursions from the least-squares line as shown in Figure 3. The percentage of samples during each quarter that exceeded the existing

effluent standard of 0.5 ppb and the proposed effluent standard of 3.0 ppb also decreased as illustrated in Figure 4 and 5. Cook and Rogers concluded that there was a trend towards appreciably lower mercury concentrations in effluents during this period. Considering that, on average, volumetric flow rates during this period were approximately constant, and, that some of the effluents considered high in total mercury actually had marked decreases in volumetric flow, one could conclude that the rate of release of total mercury mass also decreased appreciably.

From the testimony given during the Illinois Pollution Control Board (1976-77) hearings on proposed amendments to mercury effluents standards it was apparent that a number of manufacturing and service institutions had either eliminated mercury from their wastewater by pretreatment or eliminated mercury from their product or process. For example, some paint manufacturers had eliminated the use of mercury compounds as fungicides and one bleach manufacturer imposed the requirement on their chlorine source that it not be produced by a mercury-cell process. Thus, it appears that the introduction of mercury into waterways by way of sampled effluents is being reduced, in both concentration and total mass.

Rain and other runoffs into waterways are possible sources of mercury. These sources might contain mercury from coal combustion gases, including coal consumed in other states, that settles to the ground or that is precipitated with the rain. They might also contain mercury from past agricultural activities when mercury was used in seed treatment and as a general fungicide. However, because of the affinity for organic matter and certain soil components, most of the mercury would be associated with suspended matter, rather than in solution, and would eventually become part of the bottom sediment in the waterway.

Diehl, et al. (1972), Dunlap (1971), and Joensuu (1971) observed that from zero to seventy percent of the trace mercury in the combustion of coal enters the atmosphere, depending upon the design of the power plant and the associated scrubbers. Diehl, et al. calculated a possible release of as much as 300 tons per year in the United States for electrical power generation alone, based on typical trace mercury concentrations of 10 to 100 ppb. However, Anderson and Smith (1977) reported levels of 0.16 to 0.56 ppm (parts per million) in the muscle tissue of largemouth bass from Lakes Decatur, Otter, and Shelbyville in contrast to only 0.07 ppm in the muscle tissue of largemouth bass taken from Lake Sangchris — a recipient of airborne mercury from a adjacent coal-fired power plant. Furthermore, Dr. David Kenney (1976), Director of the Illinois Department of Conservation, stated that there were no known instances of mercury caused fish kills in Illinois and there have been no closures or bans on fishing in Illinois due to dangerous mercury levels in fish. There have been several advisories to limit the consumption of fish from some waters. Flemal (1976) analyzed the IEPA water quality data for all of the Illinois watersheds and found the mean mercury concentration ranged from 0.014 ppb for the upper Mississippi River (near the Wisconsin border) to 0.602 ppb for that portion of the Mississippi River near St. Clair County. Flemal's analysis for those watersheds totally within the state showed a range from 0.028 ppb to 0.172 ppb. The time trends for the IEPA stream water quality data have not yet been determined.

A number of investigators have shown that mercury in the sediment of lakes and rivers is converted into methyl mercury by microorganisms and assimilated into the food chain. Consequently, these deposits probably play a greater role in determining the level of mercury in the food chain than the total mercury in the water itself. Collinson and Shimp (1972) studied the bottom deposits in the Peoria Lake portion of the Illinois River and found the distribution of trace elements, including mercury, with respect to depth of sediment to be relatively uniform. This was quite unlike southern Lake Michigan where concentrations are limited to the uppermost 10 cm (Shimp, Leland, and White, 1970). The mercury values in the bottom sediment of Upper Peoria Lake was virtually the same as those encountered in southern Lake Michigan; from 0.1 to 0.5 pp. Probably of greater importance in determining time trends, Collinson and Shimp compared their results with analyses previously de-

rived from Lake Michigan and those known from water quality and biological studies in the Illinois River and found about the same levels of mercury. Unfortunately, historical records of mercury concentrations in bottom sediments throughout the state are scarce, and, it is not prudent to assume that mercury stays put in older sediments. Hence, one can only speculate on time trends. The IEPA is establishing a sediment study program that should, in time, answer some of the elusive questions concerning time trends of mercury concentrations in bottom sediments.

There is very little data relating to mercury levels and trends in terrestrial organisms in Illinois. We do know that there are no known cases of mercury toxicity in humans in Illinois from consumption of fish or land animals, such as pheasants and pork, although this has occurred in other states and countries. But, this lack of data does not preclude the existence of some segments of the ecosystem in Illinois with dangerously high or increasing levels. There is also insufficient data on mercury concentrations in air, particularly in or around occupational situations. Błock (1978) reported the death of a dentist and a dental assistant in Kentucky from mercury toxicity originating from mercury vapor in an occupational situation. Correspondence with health authorities in other states has revealed a number of mercury toxicity cases in humans in which occupational exposure to mercury vapors was identified, especially exposure in the cell rooms of mercury-cell chlor-alkali plants.

Recognizing that a significant void exists in available data, it can be said that presently available data does not indicate any serious or widespread trends towards increasing mercury contamination of the terrestrial or aquatic food chains in Illinois.

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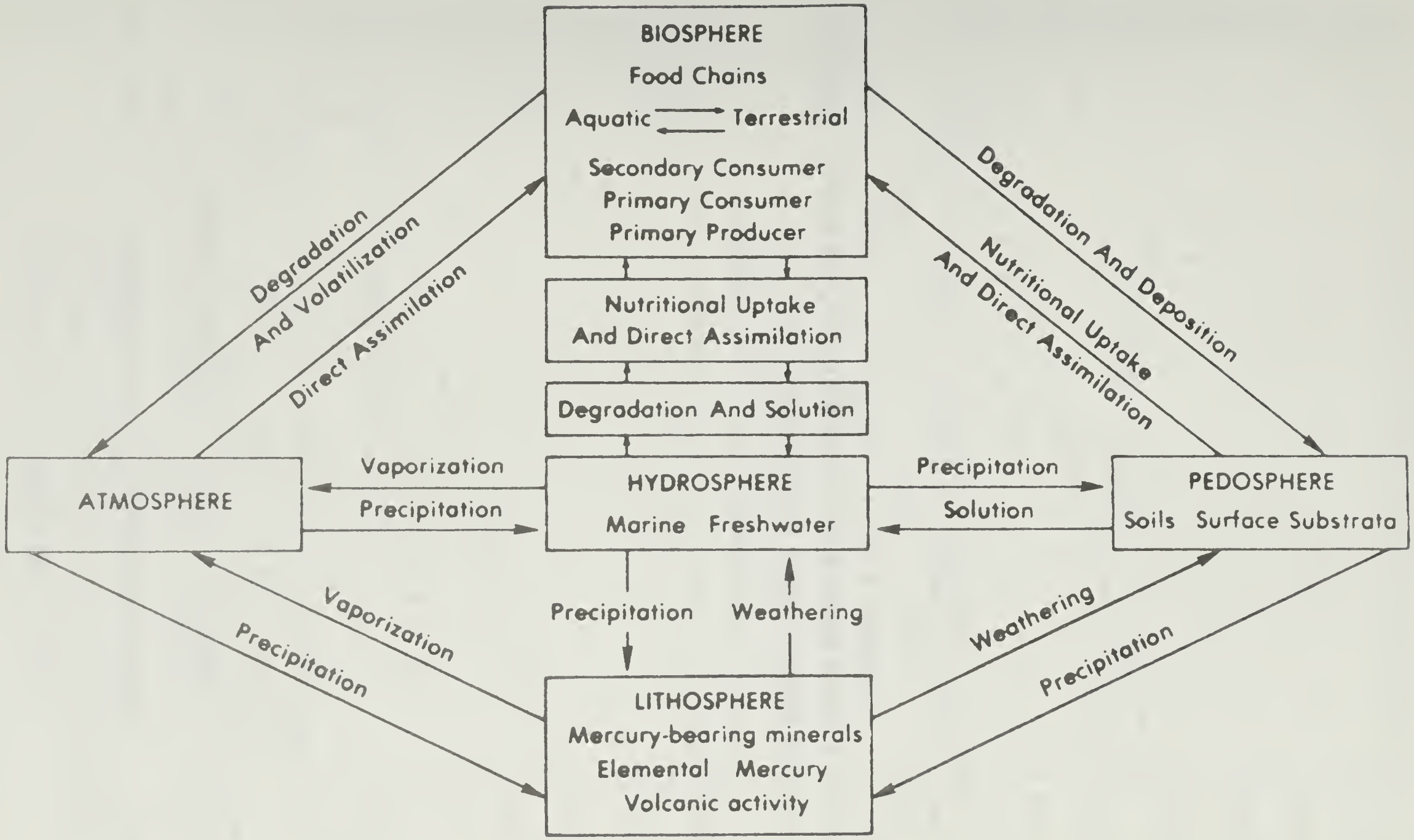

FIGURE 1. BIOGEOCHEMICAL CYCLE OF MERCURY.

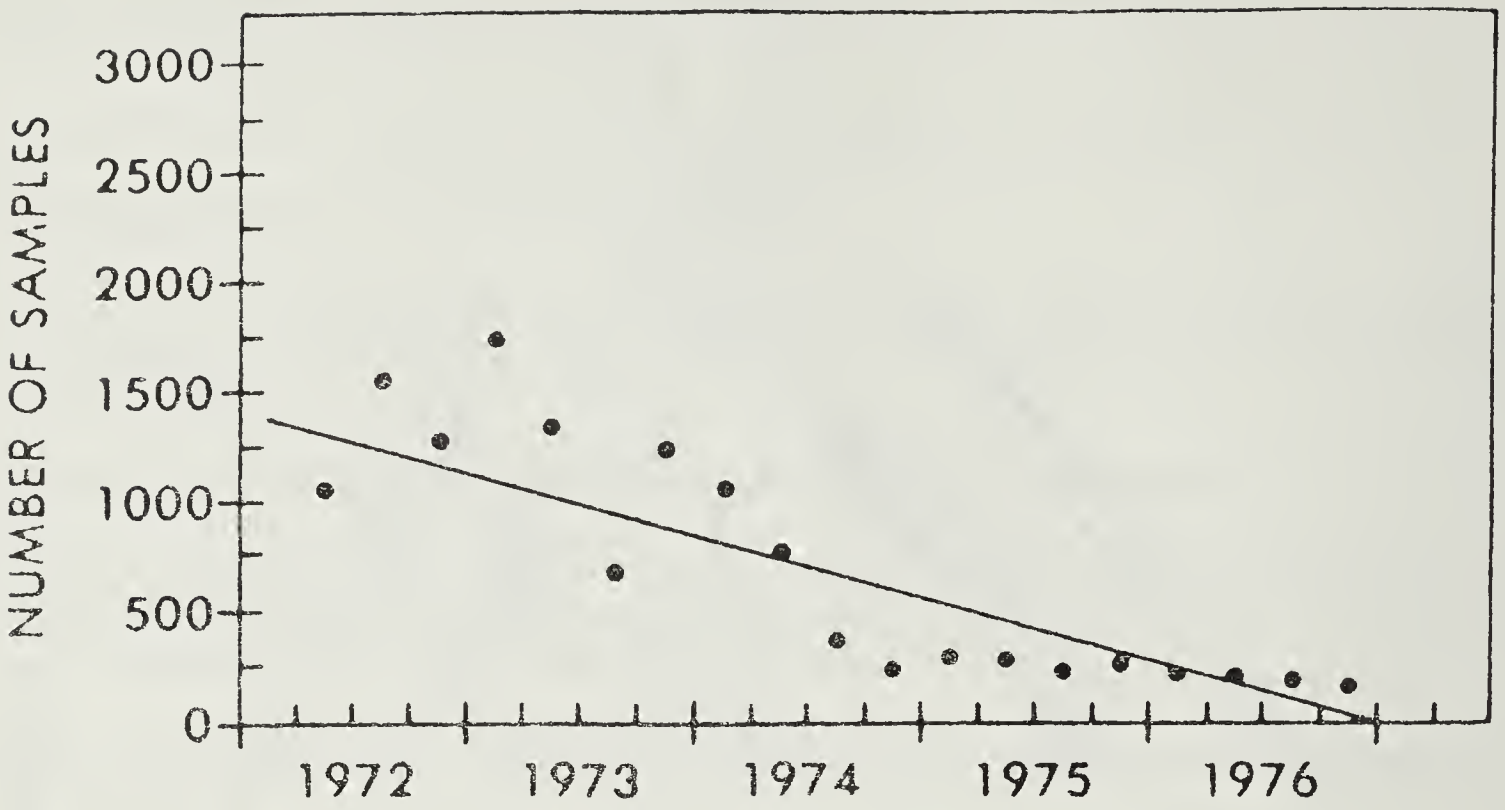

FIGURE 2. NUMBER OF IEPA EFFLUENT SAMPLES ANALYZED FOR MERCURY FOR EACH CALENDAR QUARTER FROM 1972 THROUGH 1976.

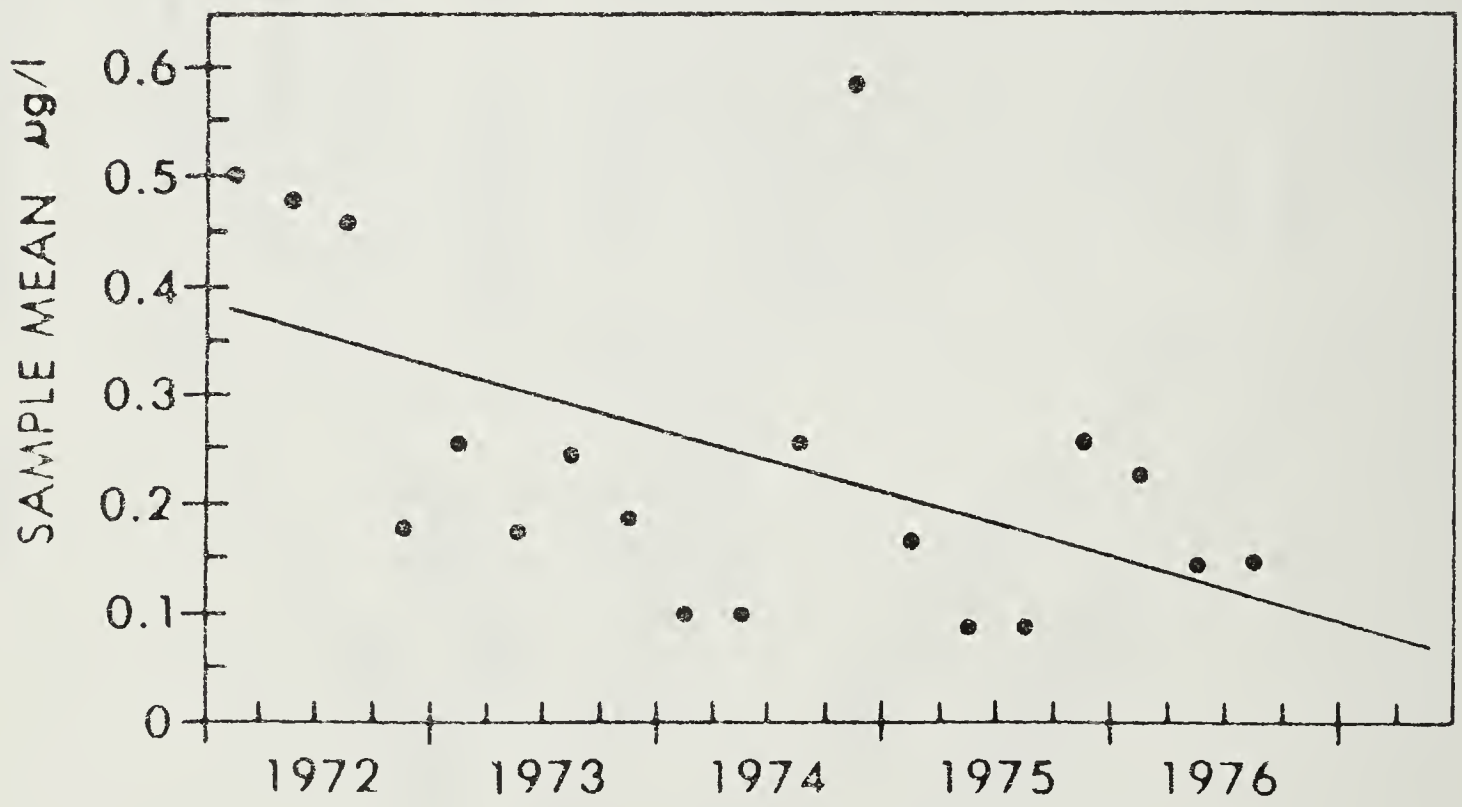

FIGURE 3. MEAN VALUE OF Hg CONCENTRATION IN EFFLUENT SAMPLES FOR EACH CALENDAR QUARTER FROM 1972 THROUGH 1976.

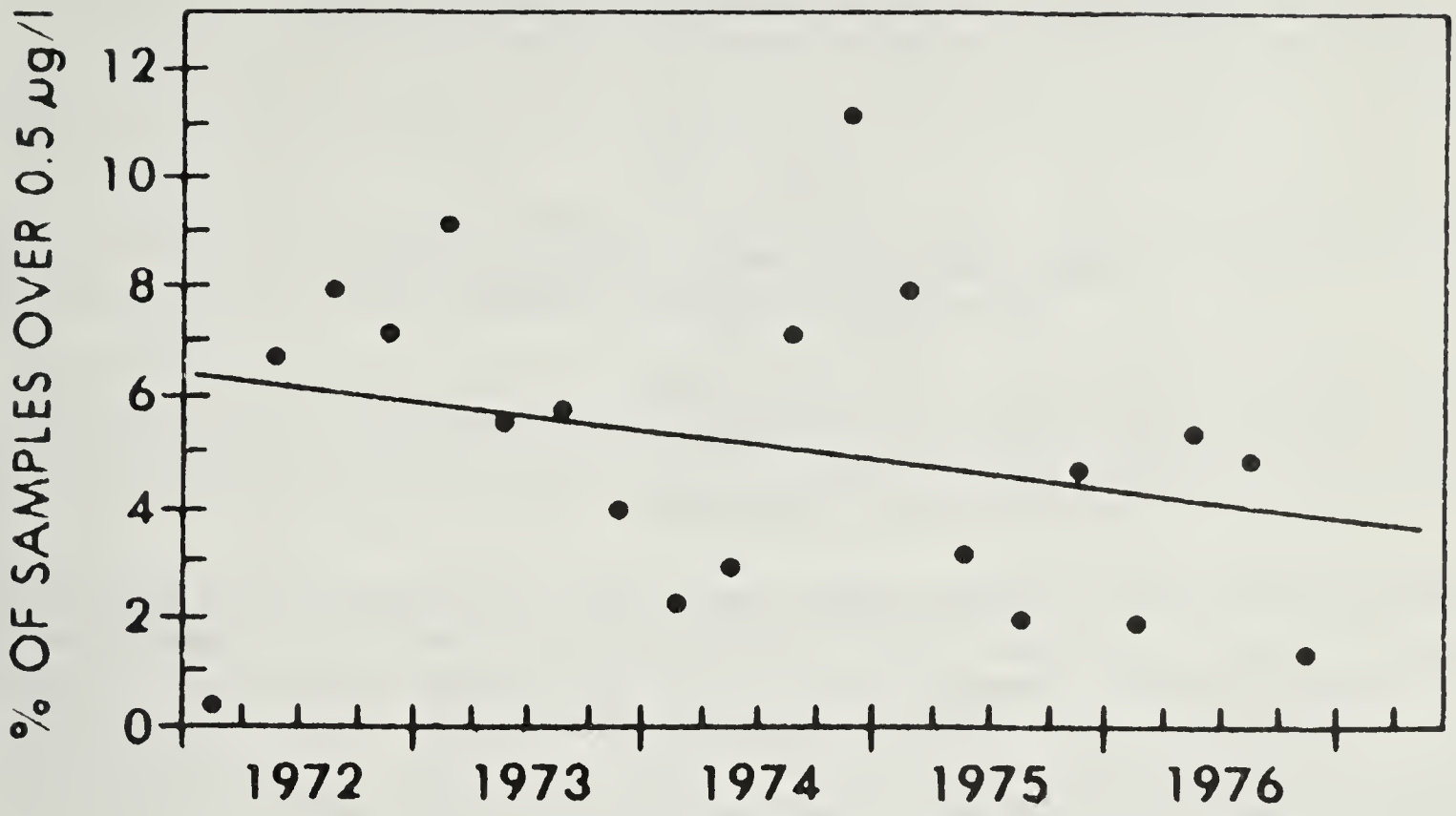

FIGURE 4. PERCENT OF EFFLUENT SAMPLES EXCEEDING 0.5 µg/l FOR EACH CALENDAR QUARTER FROM 1972 THROUGH 1976.

FIGURE 5. PERCENT OF EFFLUENT SAMPLES EXCEEDING 3.0 µg/l FOR EACH CALENDAR QUARTER FROM 1972 THROUGH 1976.

WATER QUALITY INVESTIGATION OF UPPER SALT CREEK NORTHEASTERN ILLINOIS

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ABSTRACT

The physical, chemical, and bacteriological water quality were sampled weekly at two locations in Upper Salt Creek (Northeastern Illinois) from May through December 1975. Present conditions were compared with stream standards adopted by the Illinois Pollution Control Board. Parameters which violated the standards included ammonium nitrogen, chloride, copper, cyanide, dissolved oxygen, fats, oils and greases, fecal coliform, iron, lead, mercury, silver, and total dissolved solids. Groundwater infiltration, discharges from combined and separate storm sewers, and frequent overbank flooding have contributed to the water quality violations.

INTRODUCTION

There has been a renewal of interest in the behavior of chemical and physical parameters associated with polluted streams, particularly the effects of domestic and industrial waste discharges on stream environments. Since the suitability of a water source for domestic, industrial, or recreational purposes frequently depends upon its chemical quality, such considerations have become an integral part of water resource planning and management.

Prior to this investigation, the only chemical assessment of water quality in Upper Salt Creek was that conducted by Spieker (1970). Despite the limited amount of sampling (three sampling runs), he concluded that Salt Creek was polluted in times of both low and high flows.

In the present study, samples were collected weekly for a period of eight months to determine the water quality in Upper Salt Creek, and to compare present conditions with stream standards adopted by the Illinois Pollution Control Board. The study will also provide baseline data for assessing the impact of future water quality improvements within the basin.

SITE DESCRIPTION

Salt Creek, approximately 72.4 kilometers in length, is formed by the confluence of several small streams draining surface and groundwater from the low hills west of Palatine, Illinois. Upper Salt Creek is that portion of the creek upstream from the Cook and DuPage County line (figure 1). The Salt Creek watershed encompasses 391 square kilometers, and the area of the Upper Salt Creek basin is approximately 156 square kilometers.

Developed land (defined as that which has been committed to a permanent use, i.e., residential, industrial, roads, etc.) occupies about 14 percent of the Upper Salt Creek watershed. Cropland, grassland (pastures, lawns, parks), and lowlands (forests, wetlands, flood plains), which are the principal undeveloped land use types, account for approximately 13, 52 and 21 percent, respectively.

According to USGS (1975) records, the average stream flow in 1975 at Algonquin Road was 0.87 m^3 /sec. The historical record (1973-75) for the gaging station shows that during dry weather periods, flows of less than 0.28 m^3 /sec were common. Very rapid changes in flow occurred periodically in the creek as a result of numerous precipitation events in the watersheds.

During 1974-75, there were no known sewage discharges into Salt Creek in Cook County. However, a 5.7 square kilometer area in Palatine contains combined storm and sanitary sewers which discharge periodically to Upper Salt Creek during storm periods.

The John Egan Water Reclamation Plant, Schaumburg, Illinois, began discharging a tertiary treated effluent to Salt Creek in late December, 1975. The facility is capable of removing pollutants exerting biochemical oxygen demand, as well as suspended solids, ammonium nitrogen, nitrates and phosphorus. The discharge enters the creek in the Ned Brown Forest Preserve (figure 1).

Two sampling sites were selected. Station 1 was located at the Higgins Road Bridge (Illinois Route 72), and Station 2 at the Arlington Heights Road Bridge (figure 1).

MATERIALS AND METHODS

From May 6, 1975, until December 30, 1975, weekly samples were collected from the upstream side of each bridge by lowering a 3.8 liter stainless steel bucket to a depth of 0.3 meter in the center of the creek.

The water samples were transported to the laboratory in polyethylene bottles and analyzed for the following constituents: pH, alkalinity, sulfate, chloride, total and suspended solids, conductivity, turbidity, biochemical oxygen demand, TKN, ammonium nitrogen, nitrite-nitrate nitrogen, total and soluble phosphorus, fats, oils and greases, cyanides and phenols. A portion of the sample was also analyzed for 12 metals. Dissolved oxygen samples were collected manually and fixed chemically in the field. Samples for bacteriological analyses were collected in sterile, 120 ml glass bottles.

All samples were analyzed within 24 hours in accordance with procedures set forth in the 14th edition of *Standard Methods* (1975). The nitrogen series and total and soluble phosphorus were determined using a Technicon Auto Analyzer. Metals were measured with an atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Means and ranges for the water quality parameters measured in Upper Salt Creek from May-December, 1975 are shown in tables 1-3. Considering the slight differences in the annual mean values of the chemical analyses between the two sampling stations (except for chloride and sulfate), no statistical analyses were performed.

There was little variation in the hydrogen ion concentration. The water was slightly alkaline, with pH values ranging from 6.5-8.3. The relative consistency of pH values throughout the year reflects the well buffered nature of the water. The annual mean value for alkalinity in Upper Salt Creek was 183 mg/l.

The amount of suspended and dissolved matter was quite variable during the sampling period, ranging from 12-292 mg/l (mean = 80 mg/l), and 249-1321 mg/l (mean = 596 mg/l), respectively. Much of the variability was related to fluctuations in creek discharge due to numerous precipitation events.

Dissolved oxygen exhibited a distinctive seasonal fluctuation, ranging from a mean value of 10.3 mg/l in the winter to 6.4 mg/l in the summer. The mean dissolved oxygen value for the study reach was 7.4 mg/l.

The presence of biochemical oxygen demand (BOD) ranging from 1-11 mg/l, may have resulted from overflows from either the combined sanitary or separate storm sewers. However, Hynes (1970) reported significant BOD in non-polluted streams and attributed this to various allochthonous materials, most important of which were dead leaves.

Ammonium nitrogen concentrations which may be expected in most unpolluted streams during low flow conditions are generally less than 0.2 mg/l (Klein, 1962; Davis, *et al.,* 1978). The mean, minimum, and maximum concentration of ammonium nitrogen in Upper Salt Creek was 0.4 mg/l, 0.1 mg/l, and 1.5 mg/l, respectively. Values greater than 0.2 mg/l may be attributable to either bottom scour from increased flow, natural runoff or contributions from the combined sewers.

The mean nitrate (0.43 mg/l) and phosphorus (0.19 mg/l) concentrations in Upper Salt Creek greatly exceed the level required for plant growth. However, no algal blooms were observed in the study area during the sampling period. It appears that low light availability restricts primary productivity, a light-inhibition effect. The mean value for turbidity was 46 JTU. Reduced turbidity with a resultant improvement in light penetration may contribute to increased algal growth in the future.

Fats, oils and greases are not definitive chemical categories, but include thousands of organic compounds with varying physical, chemical, and toxicological properties. The surface waters of Upper Salt Creek contained floating petroleum-derived oils as well as fats and greases of animal and vegetable origin. The mean value for the study reach was 15 mg/l. Much of the material enters the creek as urban runoff from highway drainage.

The mean concentrations of phenols (0.002 mg/l) and cyanides (0.007 mg/l) in Upper Salt Creek were those of an unpolluted river of comparable size and character.

The water component of Upper Salt Creek exhihibted low mean values of the metals surveyed, except for iron (1.3 mg/l). While metal concentrations were elevated in some cases, they were not excessive when compared to other systems which drain urban areas and receive nonpoint runoff (Colston, 1974; Whipple, *et al.,* 1976).

Total and fecal coliform densities ranged from 100-800,000/100 ml and 100-20,000/100 ml. respectively. Similarily, fecal streptococci densities varied from 70-77,000/100 ml. The variability of coliform densities was presumably a result of periodic nonpoint runoff.

The Illinois Pollution Control Board (1972) has instream water quality standards for 22 of the 34 parameters measured. The standards for 10 of the parameters were met at all times (table 4). The number of instream observations not in compliance were as follows: ammonium nitrogen, chloride, copper, cyanide, dissolved oxygen, fats, oils and greases, fecal coliform, iron, lead, mercury, silver, and total dissolved solids.

The present study reveals that less than optimal water quality was found in Upper Salt Creek prior to an effluent being discharged from the Egan treatment plant, and several apparent factors may have contributed to this situation. Groundwater infiltration, natural runoff, discharges from combined and separate storm sewers, and frequent overbank flooding, have contributed to the water quality violations in Upper Salt Creek.

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Figure 1. Map of Upper Salt Creek showing sampling stations (numbered circles).

TABLE 1. Mean Values and Ranges of Water Quality Constituents Measured in Upper Salt Creek, May Through December, 1975, Expressed in mg/l Except Where Noted

	Station #1*		Station #2**	
Constituent	Mean ***	Range	Mean	Range
Dissolved Oxygen	7.3	4.0-12.6	7.5	1.8-12.1
BOD_5	4	2-10	4	1-11
pH		6.5-8.3		6.7-8.3
Alkalinity	188	100-315	178	108-425
Chloride	94	52-570	66	38-204
Sulfate	153	55-245	198	80-490
Total Solids	663	298-1344	689	450-1146
Suspended Solids	74	12-292	86	17-219
Conductivity (umhos/cm)	691	450-1700	667	425-950
Turbidity (JTU)	43	15-94	53	18-92

* Higgins Road
** Arlington Heights Road
*** Values less than detectable limit are considered zero for calculating mean

TABLE 1. Concluded

Constituent	Station #1* Mean***	Station #1* Range	Station #2** Mean	Station #2** Range
Total Kjeldahl Nitrogen	1.4	0.02-3.3	1.3	0.5-2.8
Ammonium Nitrogen	0.4	<0.1-1.5	0.4	<0.1-1.5
Nitrite-Nitrate Nitrogen	0.4	0.02-1.8	0.5	0.07-1.5
Total Phosphorus	0.202	<0.01-0.720	0.185	0.03-0.48
Soluble Phosphorus	0.139	<0.01-0.30	0.133	0.03-0.30
Fats, Oils, and Greases	16	3-39	15	3-33
Cyanide	0.007	<0.001-0.027	0.008	<0.001-0.072
Phenol	0.002	<0.002-0.01	0.002	<0.002-0.09

* Higgins Road
** Arlington Heights Road
*** Values less than detectable limit are considered zero for calculating mean

TABLE 2. Mean Values and Ranges of Metals Measured in the Waters of Upper Salt Creek May Through December, 1975 Expressed in mg/l

	Station #1*		Station #2**	
Metal	Mean***	Range	Mean	Range
Arsenic	0.000	<0.001-0.015	0.000	<0.001-0.003
Barium	0.033	<0.100-0.300	0.055	<0.100-0.400
Cadmium	0.001	<0.02-0.020	0.001	<0.02-0.020
Chromium (Total)	0.004	<0.001-0.040	0.003	<0.001-0.040
Copper	0.008	<0.001-0.130	0.006	<0.001-0.050
Iron (Total)	1.139	0.500-2.400	1.355	0.300-3.100
Lead	0.020	<0.01-0.120	0.009	<0.01-0.050
Manganese	0.134	<0.02-0.240	0.154	<0.02-0.950
Mercury	0.006	<0.0001-0.200	0.000	<0.0001-0.001
Nickel	0.006	<0.1-0.200	0.003	<0.1-0.100
Silver	0.000	<0.01-0.010	0.00	<0.01-0.010
Zinc	0.009	<0.1-0.200	0.006	<0.1-0.200

* Higgins Road
** Arlington Heights Road
*** Values less than detectable limit are considered zero for calculating mean

TABLE 3. Geometric Means of Total Coliform, Fecal Coliform, and Fecal Streptococci Measured in Upper Salt Creek, May Through December, 1975 per 100 ml

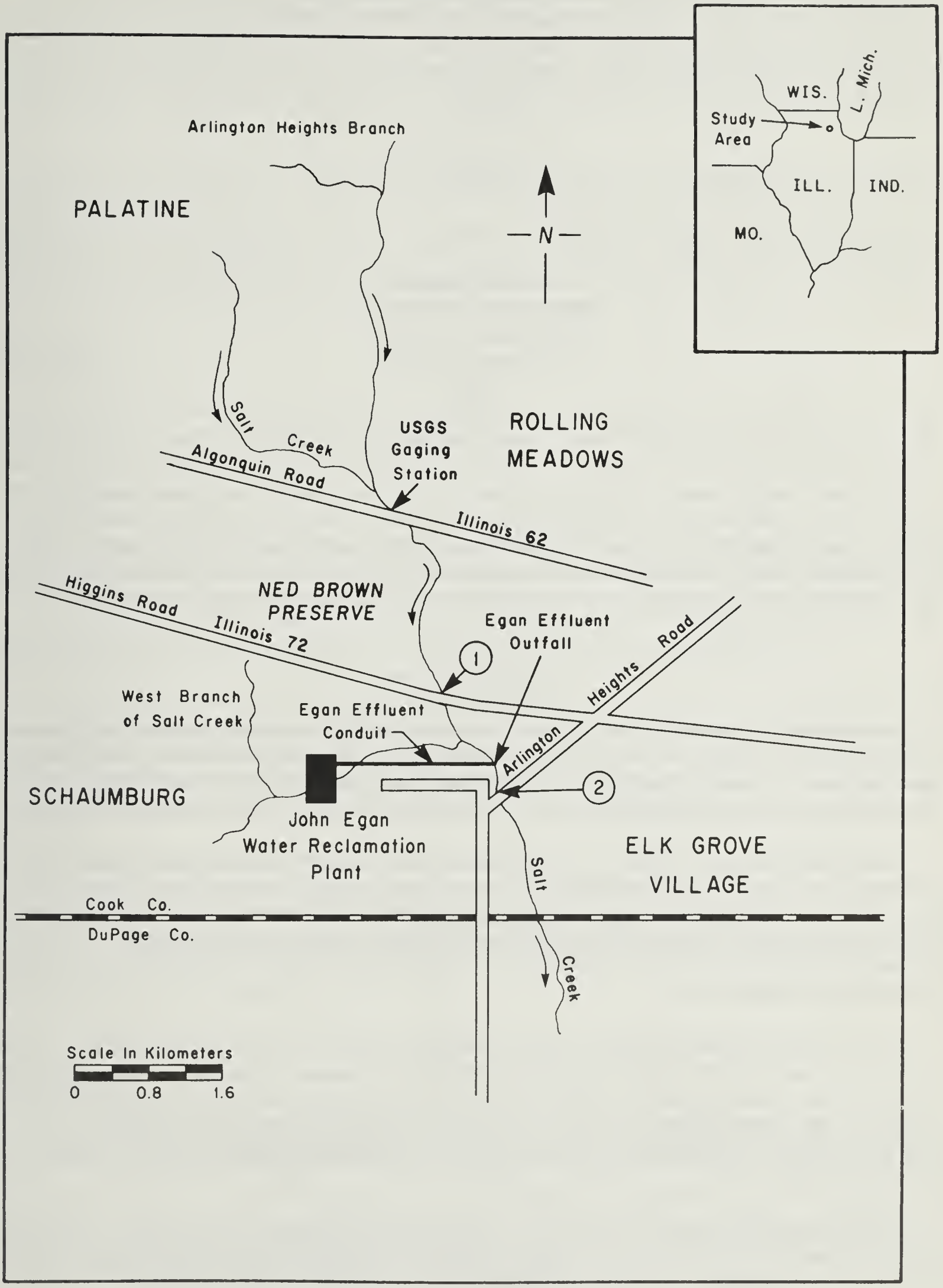
	Station #1*	Station #2**
Bacteria	Mean	Mean
Total Coliform	1.33×10^4	1.60×10^4
Fecal Coliform	6.12×10^2	8.49×10^2
Fecal Streptococci	2.16×10^3	2.50×10^3

* Higgins Road
** Arlington Heights Road

TABLE 4. Violations of Illinois Pollution Control Board's General Instream Water Quality Standards in Upper Salt Creek May Through December, 1975

Parameter	IPCB Standard	Number of observations	Number of observations not in compliance	Percent of observations not in compliance
Ammonium Nitrogen	1.5 mg/l	66	2	3
Arsenic	1.0 mg/l	66	0	0
Barium	5.0 mg/l	66	0	0
Cadmium	0.05 mg/l	66	0	0
Chloride	500 mg/l	65	1	2
Chromium	1.0 mg/l	66	0	0
Copper	0.02 mg/l	66	5	8
Cyanide	0.025 mg/l	66	4	6
Dissolved Oxygen	6 mg/l	61	14	23
Fats, Oils & Greases	15 mg/l	64	23	36
Fecal Coliform	400/100 ml*	64	64	100
Iron	1.0 mg/l	66	38	58
Lead	0.1 mg/l	66	1	2
Manganese	1.0 mg/l	66	0	0
Mercury	0.0005 mg/l	66	1	2
Nickel	1.0 mg/l	66	0	0
pH	6.5-9.0	66	0	0
Phenol	0.1 mg/l	65	0	0
Silver	0.005 mg/l	66	2	3
Sulfate	500 mg/l	65	0	0
Total Dissolved Solids	1000 mg/l	64	2	3
Zinc	1.0 mg/l	66	0	0

* 10% of the samples during any 30% day period shall not exceed standard.


Arlington Heights Branch
PALATINE
N
WIS.
L. Mich.
Study Area
ILL.
IND.
MO.
Salt Creek
Algonquin Road
USGS Gaging Station
ROLLING MEADOWS
Illinois 62
Higgins Road
Illinois 72
NED BROWN PRESERVE
Egan Effluent Outfall
1
Heights Road
West Branch of Salt Creek
Egan Effluent Conduit
Arlington
SCHAUMBURG
2
John Egan Water Reclamation Plant
ELK GROVE VILLAGE
Salt Creek
Cook Co.
DuPage Co.
Scale In Kilometers
0 0.8 1.6

MULTIPLE METHOD ESTIMATES OF FISH POPULATIONS IN A SMALL POND

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ABSTRACT

Single and multiple capture-recapture procedures were undertaken using hoop nets, gill nets, seining, and electroshocking to sample the fish populations. Multiple-method procedures were employed to study their effects on capturing selectivity and differential vulnerability to capture. Multiple procedures, which involved capture and recapture with two or more sampling methods, yielded more unbiased and accurate population estimates than single method procedures.

INTRODUCTION

Capture-recapture procedures to estimate fish populations have been developed by Peterson (1896), Schnabel (1938), Schumacher and Eschmeyer (1943), Chapman (1954), and others. Assumptions necessary to validate these procedures have been described by Ricker (1948, 1958). The frequent inaccuracies recorded reflect the inability of these assumptions to accomodate field situations.

Fredin (1950), Westers (1963), and Beukema and DeVos (1974) have proposed double method procedures to reduce the bias of differential vulnerability to capture of marked and unmarked individuals. In our study, simultaneous multiple capturing techniques were employed using hoop nets, gill nets, seining, and electroshocking to reduce capturing selectivity and recapturing bias.

MATERIALS AND METHODS

The study was conducted between March 17 and May 3, 1976 at Lincoln Log Cabin Pond, 8 miles south of Charleston, Illinois, Coles County. The Pond is 0.24 hectares in size with an average depth of 1.8 meters and a maximum depth of 3.5 meters. Electroshocking was conducted 14 times (three times a week) for 45 minute periods with boat mounted AC equipment similar to that described by Larimore et al. (1950). Fish captured were marked by removing the left pectoral fin and released at a central location.

Seining occurred 13 times using a 6.1 by 1.2 meter minnow seine with 0.64 cm mesh. A sampling period consisted of six hauls which included the entire shoreline except for the east side with submerged trees along the bank. Fish captured were marked by excising the right pectoral fin.

Hoop and gill net sampling occurred on 36 occasions. Hoop netting was accomplished with two 0.9 m diameter, 2.54 cm mesh hoop nets in conjunction with two 4.5 by 1.2 m leads placed at the middle of and perpendicular to the front hoops. Gill netting employed a 30.5 m gill net with four 7.6 meter panels of 2.5, 5.1, 7.6, and 10.1 cm mesh. The nets were placed randomly and checked every 24 hours. Fish captured were marked by removing the right pelvic fin (hoop nets) or left pelvic fin (gill nets).

Population estimates were made using the Schnabel (1938) and Schumacher and Eschmeyer (1943) formulas; confidence intervals were those of Robson and Regier (1971) and Schumacher and Eschmeyer (1943) respectively. Estimates, employing the single and multiple-methods, were made for each species for size classes 5-10.1 cm, 10.2-15.2 cm, and 15.3 cm or longer. The multiple-methods involved the cumulative data from the capture and recapture of fish using two or more capturing devices. The pond was drained at the end of the study to determine the total population.

RESULTS

The species represented included redear sunfish (*Lepomis microlophus*), green sunfish (*Lepomis cyanellus*), largemouth bass (*Micropterus salmoides*), and black crappie (*Pomoxis nigromaculatus*). The *P. nigromaculatus* population consisted of six large individuals that were repeatedly captured with hoop nets only.

Redear sunfish were sampled most effectively with hoop nets and electroshocking. Small redear sunfish were captured by electroshocking and seining only, with no recaptures occurring. Intermediate sized redear sunfish were captured most effectively with hoop nets and electroshocking. The largest individuals (Table 1) were most often taken by hoop netting. The most accurate population estimates resulted from multiple sampling with hoop nets and electroshocking (Table 1).

Largemouth bass were captured primarily by electroshocking and seining. The small bass (Table 2) population was best estimated from the multiple-methods of seining and electroshocking as well as gill netting, seining, and electroshocking. The large *M. salmoides* were most effectively sampled and estimated by electroshocking while the intermediate sized largemouth bass were not successfully recaptured as indicated by a single recapture resulting from the multiple method of seining and electroshocking.

Green sunfish were not captured frequently by gill netting; only small individuals were captured effectively by seining. The sampling of small green sunfish yielded few recaptures and erroneous estimates. Intermediate sized green sunfish were sampled by all capturing techniques; multiple and single method procedures yielding similar results. Large green sunfish were collected by electroshocking and hoop netting only.

DISCUSSION

The basic premise of the multiple-method procedures involves the simultaneous sampling of all areas of a body of water with several different sampling methods to permit the capture of most sizes and species of fish. This procedure allows for the recapture of individuals by the same procedures with which they were originally sampled, should that method be effective, as well as permitting the recapturing of those marked individuals which would ordinarily not be recaptured, or which would be recaptured in disproportionate numbers by a single method.

The advantages of multiple method sampling are clearly shown in the estimates of the intermediate and large redear sunfish, small *M. salmoides*, and large green sunfish populations (Tables 1, 2, and 3). Intermediate sized redear sunfish were accurately estimated by hoop netting, electroshocking, and many multiple method procedures. The multiple procedure of electroshocking and hoop netting, using the Schumacher and Eschmeyer formula, was particularly accurate. This combination sampled two thirds of the population and recaptured many more individuals than either of the procedures singly.

The population of large redear sunfish was effectively sampled with hoop nets and electroshocking. Electroshocking had a negative influence on recaptures. Hoop netting effectively recaptured individuals, and the multiple method of hoop netting and electroshocking yielded the most accurate results.

Electroshocking and seining both effectively sampled the small largemouth bass population but, calculated separately, ineffectively estimated the population size (Table 2). The multiple estimate combining these two capturing techniques was accurate using the Schumacher and Eschmeyer formula. The minimal number of recaptures with the single method procedures in this population and the redear sunfish populations (Tables 1 and 2) indicates that the marked individuals are less likely to be captured again by the same apparatus while recapture by the other methods is not affected.

Large green sunfish (Table 3) were captured only by electroshocking and hoop netting. The multiple-method procedure yielded accurate estimates primarily due to an increased number of recaptures. The indication here is that electroshocking adversely affected recapture by that method but did not affect recapture by hoop nets.

The inaccurate multiple-method estimates for the intermediate and large *M. salmoides* population and intermediate-sized green sunfish can be attributed to the inefficiency of more than one collecting method to effectively sample the populations. Multiple-method sampling procedures using alternative sampling devices may be appropriate for sizes and species such as these since single method sampling estimates were also inaccurate.

The population of small redear and green sunfishes were not successfully estimated. Their small size prohibited them from being effectively captured by most of the sampling devices and marking may have resulted in a large physical handicap.

The multiple-method procedures provided accurate and apparently unbiased estimates of the various species. The sampling of all the areas of the pond by varied procedures allowed for all sizes and species of fish in the pond to be effectively collected and recaptured. Eberhardt (1969) indicated that the equal probability to capture assumption is not fulfilled by the usual sampling methods. The multiple-method presented here allows the equal vulnerability to capture assumption to become a more realistic assumption.

ACKNOWLEDGEMENTS

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Table 1. Single and multiple method population estimates for redear sunfish, *Lepomis microlophus*, collected from 17 March to 3 May 1976 at Lincoln Log Cabin Pond.

	Size Categories			
	10.1-15.2 cm		15.2 cm or longer	
Sampling Procedure*	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate
E	86 ± 58	135 ± 191	--	--
H	88 ± 24	121 ± 65	36 ± 9	46 ± 35
H,E	96 ± 18	119 ± 48	40 ± 32	58 ± 39
H,G	90 ± 18	109 ± 58	36 ± 9	46 ± 35
H,S	80 ± 16	109 ± 53	--	--
G,E	86 ± 30	134 ± 190	15 ± 8	22 ± 44
S.E	112 ± 57	135 ± 156	--	--
H,G,S	83 ± 13	114 ± 55	--	--
H,S,E	65 ± 4	90 ± 30	--	--
H,G,E	93 ± 13	132 ± 54	43 ± 6	57 ± 38
G,S,E	125 ± 48	187 ± 216	--	--
E,H,G,S	67 ± 3	94 ± 32	--	--
Actual Population Size	94		66	

* E = Electroshocking; H = Hoop netting; G = Gill netting; S = Seining

Table 2. Single and multiple method population estimates for largemouth bass, *Micropterus salmoides*, collected from 17 March to 3 May 1976 at Lincoln Log Cabin Pond.

	Size Categories					
	5-10.1 cm		10.1-15.2 cm		15.2 cm or longer	
Sampling Procedure*	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate
E	168 ± 93	252 ± 504	--	--	42 ± 23	55 ± 55
S	74 ± 20	97 ± 73	--	--	--	--
G,E	94 ± 43	157 ± 222	--	--	38 ± 4	50 ± 50
S,E	124 ± 51	176 ± 124	171 ± 22	248 ± 496	237 ± 58	60 ± 60
G,S,E	120 ± 25	178 ± 119	--	--	41 ± 7	55 ± 49
Actual Population Size	117		57		48	

* E = Electroshocking; H = Hoop netting; G = Gill netting; S = Seining

Table 3. Single and multiple method population estimates for green sunfish, *Lepomis cyanellus*, collected from 17 March to 3 May 1976 at Lincoln Log Cabin Pond.

	Size Categories					
	5-10.1 cm		10.1-15.2 cm		15.2 cm or longer	
Sampling Procedure*	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate	Schumacher Eschmeyer Population Estimate	Schnabel Population Estimate
E	92 ± 64	148 ± 296	20 ± 7	30 ± 60	--	--
H	--	--	58 ± 22	67 ± 55	22 ± 4	34 ± 30
S	199 ± 180	256 ± 296	--	--	--	--
H,E	103 ± 18	168 ± 336	45 ± 8	68 ± 43	32 ± 5	36 ± 25
H,G	--	--	50 ± 26	79 ± 64	--	--
H,S	220 ± 99	327 ± 378	50 ± 11	72 ± 54	--	--
G,E	--	--	14 ± 2	20 ± 28	--	--
S,E	196 ± 122	298 ± 243	48 ± 20	70 ± 140	--	--
H,G,S	--	--	41 ± 6	64 ± 45	--	--
H,S,E	206 ± 56	313 ± 256	--	--	--	--
H,G,E	--	--	81 ± 18	125 ± 102	--	--
G,S,E	--	--	40 ± 10	42 ± 74	--	--
E,H,G,S	--	--	43 ± 4	66 ± 37	--	--
Actual Population Size	463		294		36	

* E = Electroshocking; H = Hoop netting; G = Gill netting; S = Seining

AN ENVIRONMENTAL EVALUATION
– USING BIRDS AND THEIR HABITATS –
OF THE MAX McGRAW WILDLIFE FOUNDATION IN NORTHEASTERN ILLINOIS

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ABSTRACT

An environmental evaluation of the Max McGraw Wildlife Foundation, utilizing Graber and Graber's (1976) assessment technique, revealed habitat composition on the study area was very good (18.2 times above the average for northern Illinois) and biologically rich. Woodland habitats were largely responsible for the high habitat rating while residential areas, small grain and row crops, and hayfields contributed very little toward the rating. Faunal indices — for the entire study area — were positive, although some habitat types were biologically richer than others. This assessment technique provides a means of evaluating habitat composition of an area and also allows for an approximation of the biological richness — or quality of an area to wildlife — utilizing birds as an indicator.

INTRODUCTION

The need for a standardized procedure to evaluate natural communities becomes vital as the demand for accurate impact assessment increases. The proposed standard (Graber and Graber 1976) evaluates an area from a biological standpoint using habitat composition and the presence of nesting birds as an indicator of biological richness or habitat quality. Consequently, precedence is given to ecological values rather than to traditional economic values. The purpose of this study was to conduct an environmental evaluation of the Max McGraw Wildlife Foundation (MMWF) using Graber and Graber's (1976) assessment technique.

STUDY AREA

Located in Kane Co., Illinois, along the Fox River, the MMWF is comprised of approximately 480 ha. of variable terrain (Dillon 1970). About 28 ha. is river bottomland with the dominant vegetation consisting of cottonwood (*populus deltoides*), box elder (*Acer negundo*) and willow (*Salix spp*). Along the eastern boundary are 236 ha of agricultural land, predominantly in cash-grains, mixed with annual and perennial food and cover strips set aside for wildlife. The remaining 248 ha are classified as central uplands, and are characterized by variable topography and soil types, with woodlands dominated by white oak (*Quercus alba*).

METHODS

Two types of environmental indices, a Habitat Evaluation Index (HEI) and a set of Faunal Indices were derived for the MMWF. Although derivation of the environmental indices is outlined in detail by Graber and Graber (1976), a brief review is warranted.

Derivation of the HEI

Gross habitats within the MMWF property lines were identified by an aerial photograph (1" = 330') and verified by field observations. Classification of habitats followed Graber and Graber (1976). The acreage of each habitat was determined by weighing paper (on an analytical balance) cut out from an overlay map. The ages of the different habitats were determined. For earlier successional stages, records and personnel of MMWF were helpful in providing the estimates; while the age of older wooded tracts was estimated by dividing the D.B.H. of a representative sample of trees by known growth rates.

Once the acreage and age (or replacement factor) of each habitat had been determined, the HEI was computed. First, the replacement factor of each habitat is multiplied by the changing availability factor (Graber and Graber 1976), which considers the rate at which a given habitat is increasing or decreasing on a regional or statewide basis. The product, termed the replacement availability product, is divided by the proportion of that habitat in the area of consideration. The quotients of each habitat (termed habitat factors) are summed and divided by a regional or statewide habitat factor to derive the HEI.

Derivation of the Faunal Evaluation Indices

All nesting species of birds in each habitat were recorded using the strip census method (Graber and Graber 1963) and the Checklist of Foundation Birds (MMWF 1978). Bird species recorded in each habitat received point values based upon their abundance in Illinois and the degree of specialization for a particular habitat (values from Graber and Graber 1976). From these point values, faunal evaluation indices were derived for each habitat: total species points; average species index, calculated by dividing total species points by number of species; and a faunal index, calculated by dividing total species points by the common logarithm of the number of acres. Comparison between calculated and expected faunal indices (extrapolated from graphs in Graber and Graber 1976) were recorded for each habitat with the exception of row-crops and small grain habitats. These habitats do not support faunal specialties, therefore faunal indices were not derived (Graber and Graber 1976).

Man-made impoundments (a unique habitat on the MMWF) received special consideration in the evaluation because expected values were not presented in Graber and Graber (1976). This habitat was treated as bare ground when deriving expected faunal indices (R.R. Graber, personal communication).

RESULTS AND DISCUSSION

Habitat Evaluation Index

An HEI of 18.2 was derived for the MMWF by dividing the sum of the habitat factors (4221.9) by the average factor of 231.8 for the northern region of Illinois (Table 1). For the state as a whole, the MMWF was 15.8 times as unique, again indicating superior habitat composition. An HEI of 1.0 would, for example, indicate that an area is average relative to other areas in the region.

It is apparent from Table 1 that not all the habitats contributed equally to the final HEI. The contribution of any given habitat toward an HEI is dependent upon: (1) the acreage of a particular habitat within the area of consideration, (2) the replacement factor (or age) of that habitat, and (3) the final availability factor (given in Graber and Graber 1976). If relatively high values are recorded for all three factors for a given habitat, the resulting habitat factor will also be high (see Table 1, upland forest-age classes 170 and 230).

Faunal Evaluation Indices

While the HEI measures habitat composition, faunal evaluation indices are a closer approximation of the quality or biological richness of the habitat. The first faunal index, total species points, may be high or low depending upon the total number of avian species, or the proportion of common or uncommon species present. The average species index is based upon a different concept: the number of faunal specialties (rare or uncommon species). Since faunal specialties may be an overriding consideration when evaluating natural communities (e.g. rare and endangered species), attention may be focused more on this index than on total species points. The faunal index is perhaps the best single indicator of biological richness since it accounts for varying acreages and total species points without reference to the number of species.

Cumulative values of the different faunal indices all indicated a high level of biological richness for MMWF (Table 2). The different habitats were generally rated high, or close to expected values by the three faunal indices. Two exceptions were ungrazed grass and hayfield habitats (Table 2).

Generally, the three faunal indices were in agreement in evaluating the different habitats (Table 2). Two exceptions were upland forest and residential habitats. We believe the discrepancy in faunal indices recorded for the upland forest habitat was due to an inaccurate assessment of the total acreage of this habitat in calculating the faunal index. Total upland forest habitat was not contiguous, but was scattered in 10- to 30-acre tracts. Since a basic assumption of this index — that the habitat is largely contiguous and therefore supports a larger number of avian species — was not met, the index did not accurately portray the biological richness of this habitat. In the residential habitat, the faunal index scored higher than other faunal indices, probably because total species points was high relative to the lesser acreage of this habitat.

Relationship between the HEI and Faunal Indices

A relationship between the HEI (habitat quality) and faunal indices (biological richness) was observed for the MMWF as a whole and for many of the habitats within the MMWF. Wooded habitats contributed substantially to the final HEi and were considered biologically rich (one exception was the faunal index calculated for upland woods which — as indicated — was not accurately evaluated. Ungrazed grass, hayfield, and croplands, although accounting for nearly 40% of the total acreage, contributed very little toward the final HEI and were considered biologically poor.

One exception to this relationship between habitat quality and biological richness was the man-made impoundments. Although this habitat did not contribute significantly to the final HEI, it was considered biologically rich; the unusually high faunal indices were due to high use (by avifauna) of artificial nesting structures placed over water.

The technique used in this evaluation is simple, yet provides an effective approach to environmental assessment. In conclusion, an HEI of 18.2 and high cumulative faunal indices indicate superior habitat composition and, concurrently, a high degree of biological richness for the Max McGraw Wildlife Foundation.

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Table A.1. List of breeding birds and their respective point values compiled for upland forest.

	1.	Green heron 20
	2.	Wood duck. 20
*	3.	Red-tailed hawk. 40
*	4.	Broad-winged hawk. 100
	5.	Mourning dove 10
	6.	Yellow-billed cuckoo 20
	7.	Black-billed cuckoo. 40
	8.	Screech owl 20
*	9.	Great horned owl 20
	10.	Common flicker. 10
	11.	Red-bellied woodpecker 10
	12.	Red-headed woodpecker 10
	13.	Hairy woodpecker 10
	14.	Downy woodpecker 10
	15.	Great-crested flycatcher 10
	16.	Eastern wood pewee 10
	17.	Blue jay 10
	18.	Common crow. 10
	19.	Black-capped chickadee 10
	20.	White-breasted nuthatch 20
	21.	House wren 10
	22.	Grey catbird 10
	23.	Brown thrasher 10
	24.	American robin 10
*	25.	Wood thrush. 10
	26.	Cedar waxwing 40
	27.	Red-eyed vireo 10
	28.	Warbling vireo 40
	29.	American redstart. 20
	30.	Northern oriole 20
	31.	Common grackle 10
	32.	Brown-headed cowbird. 10
	33.	Scarlet tanager. 20

34. Cardinal 10
35. Rose-breasted grosbeak. 10
36. Indigo bunting. 10
37. Rufous-sided towhee 10
38. Field sparrow 10

* These species are not included in the bottomland forest habitat — otherwise the list is identical

Table A.2. List of breeding birds and their respective point values compiled for shrub habitat.

1. Green heron 20
2. American woodcock 20
3. Mourning dove 10
4. Yellow-billed cuckoo 20
5. Black-billed cuckoo. 40
6. Downy woodpecker 10
7. Eastern kingbird. 20
8. Willow flycatcher 40
9. Least flycatcher 100
10. Blue jay 10
11. Black-capped chickadee 10
12. House wren 10
13. Grey catbird 10
14. Brown thrasher 10
15. American robin 10
16. Yellow warbler 40
17. Common yellowthroat 10
18. American redstart. 10
19. Red-winged blackbird 10
20. Common grackle 10
21. Brown-headed cowbird. 10
22. Cardinal 10
23. Indigo bunting. 10
24. American goldfinch. 20
25. Rufous-sided towhee 10
26. Chipping sparrow 20
27. Field sparrow 10
28. Swamp sparrow 40
29. Song sparrow 10

Table A.3. List of breeding birds and their respective point values compiled for residential habitat.

1. Wood duck. 20
2. Mourning dove 10
3. Screech owl 20
4. Common flicker. 10
5. Red-headed woodpecker 10
6. Downy woodpecker 10
7. Great-crested flycatcher 10

8.	Eastern wood pewee	10
9.	Barn swallow	20
10.	Blue jay	10
11.	Black-capped chickadee	10
12.	White-breasted nuthatch	20
13.	House wren	10
14.	Grey catbird	10
15.	Brown thrasher	10
16.	American robin	10
17.	Cedar waxwing	40
18.	Red-eyed vireo	10
19.	Northern oriole	20
20.	Common grackle	10
21.	Brown-headed cowbird	10
22.	Cardinal	10
23.	Chipping sparrow	20
24.	Song sparrow	10

Table A.4. List of breeding birds and their respective point values compiled for ungrazed grassland habitat.

1.	Killdeer	10
2.	Spotted sandpiper	80
3.	Mourning dove	10
4.	Horned lark	10
5.	Short-billed marsh wren	20
6.	Common yellowthroat	10
7.	Red-winged blackbird	10
8.	Eastern meadowlark	20
9.	Brown-headed cowbird	10
10.	Savannah sparrow	20
11.	Grasshopper sparrow	20
12.	Vesper sparrow	10
13.	Field sparrow	10
14.	Song sparrow	10

Table A.5. List of breeding birds and their respective point values compiled for man-made impoundments.

1.	Canada goose	40
2.	Mallard	10
3.	Blue-winged teal	80
4.	Wood duck	10
5.	Belted kingfisher	20
6.	Great-crested flycatcher	10
7.	Tree swallow	20
8.	Bank swallow	10
9.	Rough-winged swallow	10

Table A.6. List of breeding birds and their respective point values compiled for hayfield habitat.

1.	Killdeer	10
2.	Horned lark	10
3.	Red-winged blackbird	10
4.	Brown-headed cowbird	10
5.	Savannah sparrow	20
6.	Vesper sparrow	10
7.	Song sparrow	10

Table 2. Faunal indices for different habitats on the Max McGraw Wildlife Foundation

Habitat	Ha/Acres[a]	Number of Breeding Species	Total Avian Species Points			Avian Specialties		
			Total Species Points	Expected Species Points	Point Difference	Average Species Index	Expected Average Index	Point Difference
Bottomland Forest	11.8/29.4	34	510	460	+ 50	15.0	13.6	+ 1.4
Upland Forest	157.5/393.7	38	680	550	+ 130	17.9	14.4	+ 3.5
Shrub	54.8/137.0	29	560	460	+ 100	19.3	15.9	+ 3.4
Residential	25.0/62.6	24	330	345	- 15	13.8	14.0	- 0.2
Ungrazed Grass	44.6/111.5	14	250	290	- 40	17.9	20.5	- 2.6
Man-made Impoundments	36.0/90.0	9	210	30	+ 180	23.3	3.3	+ 20.0
Hayfields	13.6/34.1	7	80	130	- 50	11.4	18.1	- 6.7
Cumulative Values					+ 315			+ 18.8

[a]Derivation of the faunal indices require an acreage estimate. Therefore acreages of the different habitats are also presented.

Table 2 cont. Faunal indices for different habitats on the Max McGraw Wildlife Foundation.

Habitat	Faunal Indices: Common Log of Acreage	Faunal Index	Expected Faunal Index	Point Difference
Bottomland Forest	1.468	347	235	+ 112
Upland Forest	2.595	262	285	- 23
Shrub	2.136	262	206	+ 56
Residential	1.796	184	160	+ 24
Ungrazed Grass	2.047	122	132	- 10
Man-made Impoundments	1.954	108	15	+ 93
Hayfields	1.532	52	111	- 59
Cumulative Values				+ 193

Table 1. Habitat factors for various habitats and a habitat exaluation index (HEI) for the Max McGraw Wildlife Foundation

Gross Habitat	Hectares of Habitat in Impact Area	Replacement Factor (Age)	Final Availability Factor	Replacement Availability Factor	Part of Impact Area Acreage	Habitat Factor
Bottomland forest	3.7	45	82	3690	.0076	28.04
Bottomland forest	8.1	70	130	9100	.0167	151.97
Upland forest	67.0	30[a]	54	1620	.1386	224.53
Upland forest	6.8	50	54	2700	.0141	38.07
Upland forest	3.2	70	60	4200	.0066	27.72
Upland forest	3.3	90	60	5400	.0069	37.26
Upland forest	0.6	150	120	18,000	.0012	21.60
Upland forest	52.6	170	120	20,400	.1088	2219.52
Upland forest	22.7	230	120	27,600	.0470	1297.20
Pines	1.4	30	312	9360	.0028	26.21
Shrubs	54.8	15	66	990	.1135	112.37
Residential	19.0	25	0.1	2.5	.0393	.0983
Residential	4.3	45	0.1	4.5	.0089	.0401
Residential	1.8	100	0.1	10	.0037	.0370
Ungrazed grass	44.6	10	20	200	.0923	18.46
Hayfields	13.6	2	52	104	.0282	2.93
Small grain	23.2	1	52	52	.0480	2.50
Row crop	116.5	1	0.1	0.1	.2412	.0241
Man-made Impoundments	26.0	30	8	240	.0538	12.91
Man-made Impoundments	10.0	3	8	24	.0207	0.50
	483.2					4221.99

Regional habitat factor (for northern region of Illinois = 231.80

HEI for study area (in relation to northern region) = $\frac{4221.99}{231.80}$ = 18.21

Average habitat factor for entire state = 267.97

HEI for study area (in relation to entire state)= $\frac{4221.99}{267.97}$ = 15.76

[a] Indicates age class between 20 and 40 years. The other age classes were treated similarly.

ANAX LONGIPES HAGEN AND *NEUROCORDULIA XANTHOSOMA* (WILLIAMSON), TWO DRAGONFLIES NEW TO ILLINOIS (ODONATA: AESHNIDAE, CORDULIIDAE)

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ABSTRACT

Anax longipes *Hagen was taken from Moultrie County, Illinois, during June 1970. A second specimen was not collected. A single male* Neurocordulia xanthosoma *(Williamson) was taken from Pope County, Illinois, also during June 1970. These records are the first for each species in Illinois.*

Many groups of aquatic insects in Illinois have been the subject of comprehensive faunal studies, usually by personnel of the Illinois Natural History Survey (INHS). It is surprising, therefore, that a major order such as the Odonata has been the subject of only a few published studies. Needham and Hart (1901) treated the Anisoptera exclusive of the Corduliidae, Libellulidae, and Macromiidae and Garman (1917) treated the Zygoptera. These studies, and the Illinois records given by Needham and Westfall (1955), represent the core literature for Illinois odonates.

While compiling odonate records from the INHS collection, we became aware of recent captures of two secretive dragonflies not previously known from Illinois. An adult male *Anax longipes* Hagen was taken by WUB on 8 June 1970 from a pond at the INHS field laboratory on Lake Shelbyville in Moultrie County, approximately 5 km SSE of Sullivan. A second specimen was seen by WUB the following day, but it evaded capture. As Montgomery (1937) noted, *A. longipes* is truly striking in size and coloration and differs entirely from any other North American dragonfly. We do not hesitate to consider as valid this sight record of a second Illinois specimen. Both specimens were hawking over the pond when first sighted.

Anax longipes was sufficiently rare to cause Hine (1913) to state that "It does not appear that more than a score of specimens are in the collections of the world." In spite of Bick's (1953) comments regarding its local abundance in several states, most captures of the species have resulted in published notes. Ries and Cruden (1966) provide a recent summary of this literature. In reviewing these published data, it is apparent that most specimens come from small ponds in woodland settings, usually ponds containing some emergent vegetation. Such is the case with the INHS laboratory pond and for ponds in North Carolina (Montgomery County) and South Carolina (Chesterfield and Pickens Counties) where we also have observed this species.

A single adult male *Neurocordulia xanthosoma* (Williamson) was taken by us on 12 June 1970 from Hunting Branch of Bay Creek in the Bell Smith Springs Recreation Area, approximately 10 km N of Glendale in Pope County. The time was late afternoon and the specimen was collected by sweep-netting through herbaceous vegetation along the stream.

Neurocordulia xanthosoma is rare in most odonate collections. Williams (1976) attributed this to its crepuscular habits, brown coloration, its habitat requirements, and the habits of most collectors. Presently *N. xanthosoma* has been reported only from Kansas, Oklahoma, and Texas. We suspect, however, that it is more widely distributed than existing specimens would indicate. Many of the small creeks in the Bell Smith Springs area flow in relatively narrow channels bordered by vertical bluffs. Williams (1976) took his specimens from a similar site in Texas.

Much work needs to be done before the Illinois Odonata are known sufficiently to permit publication of a thorough faunal study. These records indicate, however, that such a study would be a rewarding one.

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THE FIRST RECORD IN SOUTHERN ILLINOIS OF *POLYGONIA PROGNE* (LEPIDOPTERA: NYMPHALIDAE)

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ABSTRACT

A southern extension of the known Illinois range of Polygonia progne *is reported.*

The gray comma, *Polygonia progne* (Cramer), was reported by Howe (1975) to occur from Nova Scotia south to North Carolina and west to Kansas and Nebraska. Klots (1951) reported that the southern edge of its range includes Illinois and Missouri. It is uncommon in Illinois, and has been recorded almost exclusively from the northern half of the state (Irwin and Downey 1973). The only previous record from the southern half of Illinois is from Elsah, Jersey Co. (Irwin and Downey 1973).

This species is bivoltine and overwinters as an adult (Howe 1975, Klots 1951). Its food plants include currant, gooseberry, and elm (Howe 1975, Klots 1951).

On 16 March 1979, we collected one adult male in the La Rue-Pine Hills Ecological Area in Union County; this represents a southern extension of ca. 100 miles of the known Illinois distribution of this butterfly. At the time of collection, the temperature was 15.5° C and the sky was clear.

The specimen is deposited in the SIU Entomology Collection, Zoology Research Museum.

ACKNOWLEDGMENTS

We wish to thank the U.S. Forest Service for permission to collect in the La Rue-Pine Hills Ecological Area. We would also like to thank M.C. Nielsen, 3415 Overlea Dr., Lansing, Michigan, for confirming our determination.

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COMPARISON OF CELLULAR AND NUCLEAR DRY MASS AND AREA OF GINGIVAL CELLS USING NORMAL AND AIR-DRIED SMEARS

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ABSTRACT

Gingival cells were studied using quantitative interference microscopy in normal and air-dried smears. The overall means for two female donors were as follows: intermediate cells with either round or oval nuclei, cellular dry mass 1556 pg, cellular area 2179 x $10^{-8}cm^2$; anucleate cells, cellular dry mass 1125 pg, cellular area 1305 x $10^{-8}cm^2$; round nuclei of intermediate cells, nuclear dry mass 55.7 pg, nuclear area 77.7 x $10^{-8}cm^2$; and oval nuclei of intermediate cells, nuclear dry mass 49.1 pg, nuclear area 69.8 x $10^{-8}cm^2$. There were no statistical differences between cellular and nuclear parameters determined using normal and air-dried smears. The means for cellular dry mass and area of intermediate cells were statistically greater than those for anucleate cells. The means for nuclear dry mass and nuclear area of round nuclei of intermediate cells were statistically greater than those for oval nuclei of intermediate cells. Methods used in interferometric studies of buccal cells in smears appear to be equally suited for the study of gingival cells in smears.

Detwiler and Pappelis (1978) reported that classification methods used to study buccal cells in smears are applicable to gingival cells in smears. Both cellular and nuclear morphology were used in that study. Intermediate cells with oval nuclei (61%) and round nuclei (29%) predominated in the smears. Gingival cells of these two types were randomly selected for study with interference microscopy. The following means were determined: cellular area, 3046 x $10^{-8}cm^2$; cellular dry mass, 1592 pg; nuclear area, 92 x $10^{-8}cm^2$; and, nuclear dry mass, 47 pg. Gingival cells were generally smaller and weighed less than buccal cells, but the nuclei in both gingival and buccal cells were similar in size and dry mass. They reviewed the literature which presented the sequence of cellular and nuclear changes as parabasal cells developed and finally became anucleate, superficial cells. Most interferometric studies of buccal cells have used normal smears of live cells mounted in water and air-dried smears which are hydrated at the time the slides are to be studied. Pappelis and Pappelis (1972) were the first to use air-dried smears for the study of exfoliative oral cytology using quantitative interference microscopy. Air-dried smears have not been used in the interferometric study of gingival cells.

We initiated this study to test the following hypotheses: there is no statistical difference in means for cell area, cell dry mass, nuclear area, and nuclear dry mass measurements of gingival cells determined for cells in normal and air-dried smears prepared using the same sample of cells; there is no statistical difference between cellular dry mass and cellular area means of intermediate and anucleate gingival cells; and, there is no statistical difference in nuclear dry mass and nuclear area means of round and oval nuclei in intermediate cells.

MATERIALS AND METHODS

Gingival cells were obtained from two of the authors (CKP, female, age 18; CL, female, age 22) by light rubbing action of the index finger on the outer surface of the upper gum above the incisors. Cells were transferred to slides by touching the glass lightly. One slide was processed immediately and another was stored in a dessicator over drierite for seven days. Cells were mounted in water, coverglass applied to minimize bubble formation, and the coverglass was sealed to the slide with paraffin oil. Twenty cells (five of each type) were selected for study as follows: intermediate cells with either round or oval nuclei; intermediate cells with round nuclei, intermediate cells with oval nuclei; and, anucleate cells.

Optical path differences were obtained for cells and nuclei using a Leitz transmitted light interference microscope and monochromatic light (546 nm). Photomicrographs of cells and nuclei (500x) were used to determine cellular and nuclear areas. Cellular and nuclear dry mass was computed as described by Pappelis and Pappelis (1972). Five replicate means or combinations of all means were compared using the pair t statistic and 0.05 probability level of significance for two-tailed test.

RESULTS AND DISCUSSION

There were no statistical differences between the means for the four cellular and nuclear parameters obtained from normal and air-dried smears. Because of this discovery, we used the data from both types of smears for subsequent statistical studies. We conclude that gingival cells can be studied using air-dried smears for quantitative interferometry. This method will greatly aide the study of cellular and nuclear changes that occur in gingival cells as they undergo development, maturation, and senescence.

When the data for both donors were combined (100 measurements on each cellular or nuclear parameter studied), the means were as follows: intermediate cells with either round or oval nuclei, cellular dry mass 1556 pg, cellular area 2179 x $10^{-8}cm^2$; anucleate cells, cellular dry mass 1125 pg, cellular area 1305 x $10^{-8}cm^2$; intermediate cells with round nuclei, nuclear dry mass 55.7 pg, nuclear area 77.7 x $10^{-8}cm^2$; and, intermediate cells with oval nuclei, nuclear dry mass 49.1 pg, nuclear area 69.8 x $10^{-8}cm^2$. Means for cellular dry mass and area for intermediate cells were statistically greater than those means for anucleate cells. Similarly, the means for nuclear dry mass and nuclear area for intermediate cells with round nuclei were statistically greater than those for intermediate cells with oval nuclei.

The cellular and nuclear dry mass means for the two donors were statistically different, but those for cellular area and nuclear area were not (Table 1). The cellular areas for these donors were less than those reported for Detwiler (cellular area 3046 x $10^{-8}cm^2$) but the cellular dry mass for the two donors in this study were in good agreement with that reported for Detwiler (1592 pg) (Detwiler and Pappelis 1978). Several factors could account for these differences in cell size: location of samples, i.e., front versus side of upper gum; age differences; sex differences; or, physiological status of the gingival tissue. There is no literature on factors affecting cell size in gingival tissue.

In the case of means for nuclear dry mass, the data in this study and that presented for Detwiler are in close agreement, especially for intermediate cells with oval nuclei. The oval type was the predominant cell type observed in smears from Detwiler and the nuclear dry mass for combined intermediate cells was 47 pg. The nuclear dry mass mean for intermediate cells with round nuclei presented in this study is almost identical to that reported by Lee *et al.* (1974) for buccal cells.

The means for nuclear area in this study are lower than that from Detwiler and Pappelis (1978) but variations in nuclear area have been observed for buccal cells (Lee *et al*. 1974). More data on gingival cells is needed before any conclusions about variations in this and other cellular and nuclear parameters can be drawn.

We conclude that air-dried smears can be used to study gingival cells and that these should be expected to undergo changes similar to those already reported for buccal cells. There is a need to expand the study of oral cells using both quantitative interferometry and analytical cytochemical methods. Whether the subtle changes in cellular and nuclear dry mass and area can be correlated with macromolecule changes remains to be determined.

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FIRST CONFIRMED RECORDS OF FISH (*COTTUS BAIRDI*) FROM TROUT PARK NATURE PRESERVE (ELGIN BOTANICAL GARDENS) SINCE PARK PERTURBATION BY I-90 CONSTRUCTION, 1957

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ABSTRACT

The occurrence of fish in the Trout Park Nature Preserve in Elgin, Illinois, is officially reported for the first time. Six individuals of the mottled sculpin, Cottus bairdi, *were collected. Physical restrictions, lack of intensive sampling, and former periods of erosional impacts account for fish not being previously reported.*

In the northern portion of Elgin, Kane County, Illinois, exists a series of unique brooks which form from seepage rivulets from the east bluff of the Fox River (Evers & Page, 1977). The brooks are presently contained within the confines of Trout Park Nature Preserve. Collections of macroinvertebrates, especially caddisflies, have been reported from the park; with seven of the Trichoptera species that occur in the park having not been recorded from elsewhere in the state (Ross, 1944). Additionally, a riffle beetle species (*Optioservus ovalis*) collected from the park has only been collected from two other localities in the state (Unzicker and Sanderson, 1974). No records from the Illinois Natural History Survey confirm the presence of fish species in the park's brooks (Page, 1979, pers. comm.), although reports of mottled sculpin and brook stickleback are noted (see Evers and Page, 1977). These occurrences may have been noted prior to the routing of I-90 through the largest and biologically richest area of the park in 1957.

In a reconnaissance survey (15 Sept. 1979) four mottled sculpins, *Cottus bairdi* (Pisces: Cottidae), were collected. The fish were collected by dip-netting the sides of a brook in a rubble-bottomed riffle area covered with abundant fallen tree branches. The portion of the brook where the fish were collected was 3.58 m wide (branch covered area 1.79 m wide) with depths of 5.8 to 11.4 cm. Brook velocity in the main channel was 72. 4 cm/sec and in the branched area 33.5 cm/s. Water temperature was 11.0° C. The section of the brook where the fish were collected was located 252 m upstream from its entrance to the Fox River.

Standard length and (total length) of the fish were: 77.0 (95.0), 37.0 (46.3), 29.3 (37.3), and 24.7 (31.6) mm. Based upon age group data given by Ludwig and Norden (1969) the smaller three fish were probably age group 0, while the largest fish was age group III, or possibly II. Considering the

sandy, shallow nature of the lower 30 m of the brook, it would seem unlikely that even small fishes such as minnows and sculpins would successfully move into the brook system from the Fox River during most of the year. Two explanations can therefore be presented for the occurrence of the sculpins in the brook system. First, it is hypothesized that during spring runoff, bank flooding by the Fox River would allow passage of smaller fishes into the brook. Considering the disproportionate sizes of the collected fish, and the low number collected, it is likely that the larger sculpin (female, as determined by lack of genital papilla) was gravid and moved into the brook to spawn. The smaller specimens may have been some of her offspring remaining from the spring spawn. As sculpins have been reported to exist in the nature preserve (see Evers and Page, 1977), the second possibility is that not all sculpins were eliminated (along with a portion of the park) by the construction of I-90. A small reproducing remnant population may have survived the impacts from interstate construction, with the current population now limited to the brook reach to be discussed below. The second alternative may be more plausible as the drainage structure leading to the culvert under Duncan Avenue (the downstream portion of the brook within the actual park boundary) makes upstream fish passage extremely difficult even during periods of high flooding. Two additional young-of-the-year were collected (and released) on 27 October 1979 from the same sampling area. Their total lengths were 48 and 52 mm.

Fish were not found further upstream in the brook, due to blockage from fallen trees and branches. The lower reach of the brook is not preferred sculpin habitat, being mostly sand and pebble bottomed. In the lower 100 m stretch of the brook, two brook sticklebacks (*Culaea inconstans*) and a creek chub (*Semotilus atromaculatus*) were collected. Prime habitat for the mottled sculpin is gravelly or rocky riffles (Smith, 1979). Only 26.5 m of the brook has this type of habitat, being bound by sandy substrates on the downstream end and impassable reaches upstream. Abundant macroinvertebrates, dominated by isopods and amphipods, exist in the reach to support the sculpins.

The lack of collection records for fish in the Trout Park Nature Preserve is due to several factors. First, extensive aquatic sampling has never been performed in the park, with the sampling that has been done being directed mainly at the insects of the brook. Secondly, only one of the five small brooks in the park has a direct outflow to the Fox River, coupled with depths and lengths adequate to sustain fish. However, as mentioned, even the main brook has limited available habitat. Erosion and sedimentation also undoubtedly operated in keeping fish from inhabiting the brook. During the sixties through late seventies, a storm sewer outlet emptied into the upstream end of the main brook. The impacts associated with the sewer were the creation of a muddy stream and series of small, silt-bottomed ponds (Unzicker and Sanderson, 1974). The sewer outlet was extended out of the park around 1977 (Paulson, 1979, pers. comm.). No follow-up surveys have been performed to date to determine if the main brook has returned to conditions similar to the other non-impacted brooks in the park. However, our visual observations indicate that the main brook is again flowing clear, which would make the brook more inviting to a sculpin chancing by the outlet.

Smith (1979) states that the mottled sculpin is common in the Fox River tributaries, but its habitats are being rapidly destroyed by stream alterations. Efforts to remove the sewer outlet from Trout Park Nature Preserve have therefore benefited the mottled sculpin by providing a habitat free from detrimental impacts and predation which may have otherwise limited the sculpin's ability to survive in the small brook system.

The *Cottus bairdi* specimens have been placed in the fish collection of Western Illinois University, Department of Biological Sciences, Macomb, Illinois, under the curatorship of Dr. Larry A. Jahn. No catalog numbers are provided for the specimens, but instead the fish are stored by family with alphabetical arrangement by genus.

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A Linear Delay Partial Differential Equation, I

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Abstract: The delay partial differential equation

$$u_t(x,t) = c\Delta u(x,t) - \int_{-\infty}^{0} g(t - s)\Delta u(x,s)ds$$

arises in several physical problems. This paper studies this equation by formally converting it into a new equation. Using semigroup theory the new equation is shown to have a solution. An infinitesimal generator is found for this problem, and its spectrum is computed.

1. INTRODUCTION

Functional differential equations have been well studied by various authors. Such equations arise in physical models where the rate of change of a system depends not only on the present state of the system, but also on the past state or "history" of the system. A natural generalization of functional differential equations, which are ordinary differential equations where the derivative depends on the history of the system [8], are equations involving both partial derivatives and the history of the system. These equations occur as models in some physical and biological problems. In this section models of 1. Gene frequency, 2. Heat conduction, and 3. Viscoelasticity will be considered.

1. Gene frequency

Fleming [7] has used the equation

$$\frac{\partial p}{\partial t} = \frac{\partial^2 p}{\partial x^2} + \alpha p - \beta \tag{1.1}$$

to describe the frequency of a selectively-neutral gene, in a habitat consisting of a number of colonies of animals arranged in a row. Here $p(t, x)$ is the frequency of the given gene type at time t and position x, α is a positive constant depending on the rate of reproduction and death, and β is a positive constant. The migration from colony to colony is

$$\frac{p(t, x + h) + p(t, x - h) - 2p(t, x)}{2h^2}$$

which is approximated by $\frac{\partial^2 p}{\partial x^2}$. Note that this model assumes that the rate of change of the gene frequency depends on the migration at the present moment only. To take into account the past migration, the model

$$\frac{\partial p}{\partial t} = \frac{\partial^2 p}{\partial x^2} + \int_{-\infty}^{t} g(t - s)\left(\frac{\partial^2 p}{\partial x^2}\right)(s, x)ds + \alpha p - \beta \tag{1.2}$$

where $g(s) \to 0$ as $s \to \infty$, $g(s) \geq 0$, may be considered. This integral involves the past history, and thus takes into account the rate of migration in past times. Since $g(s) \to 0$ as $s \to \infty$, the system is of fading memory type. That is, although the value of p in the distant past may affect the integral, it does so less than the value of p in the immediate past.

This model also assumes that the colonies are arranged in a row. Probably a more frequent situation would be colonies arranged in a plane. By reasoning similar to that in the preceding model, this can be represented by

$$\frac{\partial p}{\partial t} = \Delta p + \int_{-\infty}^{t} g(t - s)\Delta p(s, x)ds + \alpha p - \beta \tag{1.3}$$

where Δ indicates the Laplacian in the space variables and all variables have the same meaning as before, except x is a two vector.

2. Heat conduction

Jace W. Nunziato [12] has studied a similar equation as a model to heat conduction in materials with memory. Let M be a homogeneous heat conductor with memory. For each $x \in M$, there are three response functionals: the free energy E, the entropy

N, and the heat flux Q. Each of these depend on the temperature T and the temperature gradient ∇T, both at the present time and past history.

To be more specific, let

$$T_t(s) = T(s - t) \quad \text{and} \quad \nabla T_t(s) = \nabla(s - t),$$

considered as elements of a function space. Let $H = \{g : (-\infty,0) \to R$ such that $\int_0^\infty g(-s)h^2(s) < \infty\}$, identifying functions equal except on sets of measure 0. Here h(s) is a positive function decreasing to zero as $s \to \infty$. T(x, t) is the temperature at position x, time t. T(t) is the same function considered as a function from the real numbers into a Hilbert space H. For each t, $T(\cdot, t) \in H$. Let $\langle\ ,\ \rangle$ be the inner product in H. Then Q (similarly E and N) is a function of

$$(T, \nabla T, T_t, \nabla T_t) \in R \times H \times R^3 \times H^3.$$

E is assumed twice Fréchet differentiable, N and Q each once Fréchet differentiable.

Define G = E + TN, where G is the internal energy. Then G and Q must satisfy the energy balance equation

$$G = -\nabla Q + r \tag{1.4}$$

where r is the heat supply from the body's surroundings.

The second law of thermodynamics gives the Clausius-Duhem inequality [2]

$$\dot{N} \geq \frac{r}{T} - \nabla\left(\frac{1}{T} Q\right). \tag{1.5}$$

To obtain constitutive equations these equations are linearized. This gives after considerable computation

$$Q = -K(0)\nabla T - \int_0^\infty K'(s)\nabla T(t - s)ds. \tag{1.6}$$

In the same way

$$G = G_0 + \alpha(0)T + \int_0^\infty \alpha'(s)T(t - s)ds. \tag{1.7}$$

Here K is the heat conduction relaxation function and α is the energy temperature relaxation function.

Combining these equations and using the energy balance equation results in

$$\alpha(0)\dot{T}(x, t) + \int_0^\infty \alpha'(s)\dot{T}(x, t - s)ds = K(0)\nabla^2 T(x, t) + \int_0^\infty K'(s)\nabla^2 T(x, t - s)ds + r(x, t). \tag{1.8}$$

If $\alpha'(s) = 0$ (that is, if the energy temperature relaxation function is constant) then the equation becomes

$$\dot{T}(x, t) = \alpha\nabla T(x, t) + \int_0^\infty g(s)\Delta T(x, t - s)ds + r(x, t) \tag{1.9}$$

an equation similar to (1.3). Paul Davis has studied this equation [5], [6].

3. Another example is furnished by linear viscoelasticity of the Boltzmann type, considered by Dafermos [4] and Coleman [3]. Consider a one-dimensional homogeneous body with constant density $p > 0$. Let

$$\sigma(x, t) = \text{stress at position } x \text{ and time } t. \tag{1.10}$$

$$u(x, t) = \text{displacement from position } x \text{ at time } t. \tag{1.11}$$

Let the material satisfy the constitutive equation

$$\sigma(x, t) = cu_x(x, t) - \int_{-\infty}^{t} g(t - \tau)u_x(x, \tau)d\tau \tag{1.12}$$

where $g(\xi) \geq 0$, $g'(\xi) \leq 0$, and $c - \int_0^\infty g(\xi)d\xi > 0$, c a positive const.

The body has endpoints b and d, which remain fixed, so $u(b, t) = u(d, t) = 0$, for all $t \in R$.

The state of the body at time t is described by the displacement $u(x, t)$, the momentum $v(x, t)$, and the history of the displacement.

Here, the equation of motion becomes

$$\rho\ddot{u}(x, t) = cu_{xx}(x, t) - \int_{-\infty}^{t} g(t - \tau)u_{xx}(x, \tau)d\tau. \tag{1.13}$$

This is the same type of equation as (1.3).

In this paper and subsequent papers equations similar to (1.3) will be studied. In this paper existence and uniqueness is shown for a related equation. Then a semigroup will be defined using the solutions to this equation, and its infinitesimal generator is computed. In the last section, the spectrum of the infinitesimal generator is computed.

2. EXISTENCE, UNIQUENESS, AND THE INFINITESIMAL GENERATOR

This paper will be concerned with some partial differential equations with delay, for example

$$\frac{\partial u}{\partial t}(x, t) = c\Delta u(x, t) - \int_{-\infty}^{0} g(t - s)\Delta u(x, s)ds \tag{2.1}$$

for $t \geq 0$, where u is a scalar function of $x \in R^n$ and $t \in R$. g is a scalar function defined on $(-\infty, 0]$ and c is a positive real number.

Let Ω be an open, bounded, connected subset of R^n with boundary $\partial\Omega$. Let $\overline{\Omega}$ be the closure of Ω. Let $\partial\Omega$ be locally Lipschitz, that is, if $x \in \partial\Omega$, there is a neighborhood U_x of x in R^n such that $U_x \cap \partial\Omega$ is the graph of a Lipschitz function. By this we mean the following: A Lipschitz function is a function f such that there is a $K > 0$ for which

$$|f(x) - f(y)| \leq K|x - y|$$

for any x, y in the domain of f. Let points in R^n be represented in the usual way by an ordered n-tuple $\langle x_1, \ldots, x_n \rangle$. For at least one of these components x_r there is a Lipschitz function f such that $f(\langle x_1, \ldots, x_{r-1}, x_{r+1}, \ldots, x_n \rangle) = x_r$ in the set $\partial\Omega \cap U_x$. This is basically a smoothness condition on $\partial\Omega$ [1]. Together with (2.1) we impose the following initial-boundary conditions:

$$\begin{aligned} (2.2) \qquad & u(x, t) = 0 && x \in \partial\Omega, \quad t \geq 0 \\ & u(x, t) = w(x, t) && x \in \overline{\Omega}, \quad t \leq 0 \end{aligned}$$

where $w(x, t)$ is a given function.

The solutions to (2.1) found here will be solutions in the sense of distributions, or "weak solutions" [11], with the solution $u(x, t)$ defined on a Sobolev space [1].

Now we will define the Sobolev spaces of which we will make the most extensive use. Let $C_0^\infty(\Omega)$ be the class of infinitely differentiable functions with compact support in Ω which have for range a subset of R, and define $|u|_{H_0^1} = \sqrt{\int |\text{grad } u|^2}$. Let

$H_0^1(\Omega)$ be the completion of C_0^∞ in the norm $|\cdot|_{H_0^1}$. Then $H_0^1(\Omega)$ is a Hilbert space [11]. The Laplacian is defined on C_0^∞ and can be extended to a closed self-adjoint operator on a dense subset of $H_0^1(\Omega)$ [11].

Still another Banach space is needed.

Let $L_{2,e^{at}}[-\infty, 0; H_0^1(\Omega)]$ be the Hilbert space of functions from $(-\infty, 0]$ into $H_0^1(\Omega)$ with inner product

$$\langle f, g\rangle_x = \int_{-\infty}^{0} e^{2at}\langle f(t), g(t)\rangle_{H_0^1}\, dt \tag{2.3}$$

where $\langle\ ,\ \rangle_{H_0^1}$ is the inner product in $H_0^1(\Omega)$.

The space $H_0^1(\Omega)$ is used to correspond to the boundary condition

$$u(x,\ t) = 0,\quad x \in \partial\Omega,\quad t \geq 0.$$

Elements in $C_0^\infty(\Omega)$ certainly satisfy this condition, and so by the trace theorem [11], the condition $u(\cdot,\ t) \in H_0^1(\Omega)$ corresponds to $u(x,\ t) = 0$. Let

$$X = L_{2,e^{at}}(-\infty,\ 0;\ H_0^1(\Omega)) \times H_0^1(\Omega). \tag{2.4}$$

X will be used as the space from which the initial condition will be taken. If $(w,\ p) \in X$, $w \in X$, $p \in H_0^1(\Omega)$, then $u(x,\ t) = w(x,\ t)$ for $t < 0$, and $u(x,\ 0) = p(x)$. Since $w \in L_{2,e^{at}}(-\infty,\ 0;\ H_0^1(\Omega))$ does not imply w is continuous, both $w(x,\ t)$ for $t < 0$ and $w(x,\ 0)$ must be specified.

The first question concerning (2.7) and the initial boundary condition (2.2) is naturally, "Does a solution exist and if so, is it unique?" To show (2.1) with (2.2) has a solution in the sense of distribution, we will use semigroup theory [10].

By a semigroup of operators on a Banach space E [10], let us understand a one parameter family of continuous linear operators on the space, such that T(t) is defined for $t \geq 0$,

$$T(t + s) = T(t)T(s) \quad \text{for} \quad t,\ s \geq 0 \tag{2.5}$$

(2.6) For any fixed x, T(t)x is a norm continuous function in t.

(2.7) $T(0) = I$, the identity operator on E.

The infinitesimal generator of the semigroup $T(t)$ is defined by

$$A(x) = \lim_{t \to 0^+} \frac{T(t)x - x}{t}, \quad x \in D(A), \tag{2.8}$$

where the domain of A, $D(A)$, is given by

$$D(A) = \{x \mid \lim_{x \to 0^+} \frac{T(t)x - x}{t} \text{ exists}\}.$$

It can be shown that A is a closed linear operator with dense domain and that the semigroup is uniquely determined by the infinitesimal generator [10]. If A is an infinitesimal generator, the semigroup generated by A will be denoted by e^{At}.

Next, we will formally derive a modified equation from (2.1) and find solutions of it. These solutions will then be used to define the needed semigroup.

3. THE MODIFIED EQUATION

Let E be a Banach space and A the infinitesimal generator of a semigroup on E. Let $a \geq 0$, set $W = L_{2,e^{at}}(-\infty, 0; E)$. The Banach space E in application can be chosen to correspond to boundary conditions; for instance, as previously mentioned, $H_0^1(\Omega)$ will correspond to (2.2).

Now consider the equation

$$\frac{\partial u}{\partial t} = cAu - \int_{-\infty}^{t} g(t - s)Au(s)ds \tag{3.1}$$

where g is differentiable

$$\int_0^\infty |g(s)|^2 e^{2as} ds < \infty \,, \quad \text{and} \tag{3.2}$$

$$\int_0^\infty |g'(s)|^2 e^{2as} ds < \infty$$

for some $a > 0$.

Suppose that this equation has a solution for any initial condition (w, p), $w \in W$, $p \in E$. Then the variation of constants formula for semigroups [9] gives

$$u(t) = e^{cAt}p + \int_0^t e^{cA(t-s)} \left(\int_{-\infty}^s g(s - s')Au(s')ds'\right)ds \tag{3.3}$$

for $t > 0$. Formally integrating by parts gives

$$\begin{aligned} u(t) = e^{cAt}p &+ \frac{1}{c}\int_{-\infty}^t g(t - s)u(s)ds \\ &- \frac{1}{c} e^{cAt}\left(\int_{-\infty}^0 g(-s')u(s')ds'\right) - \frac{g(0)}{c}\int_0^t e^{cA(t-s)}ds \\ &- \frac{1}{c}\int_0^t e^{cA(t-s)}\left(\int_{-\infty}^s g'(s - s')u(s')ds'\right)ds. \end{aligned} \tag{3.4}$$

This equation will be studied now. First, it will be shown that equation (3.4) has a unique solution for (w, p), $w \in W$, $p \in E$.

Lemma (3.5). Let $w \in L_{2,e^{at}}(-\infty, 0; E)$. Then $G(t) = \int_{-\infty}^0 g(t - s)w(s)ds$ is a continuous function of t for $t \geq 0$.

Proof: For any $t_1, t_2 \geq 0$, $|G(t_1) - G(t_2)| \leq$

$$\left|\int_{-\infty}^0 (g(t_1 - s) - g(t_2 - s))w(s)ds\right| \leq \left(\int_{-\infty}^0 |g(t_1 - s) - g(t_2 - s)|^2 e^{-2as} ds\right)^{\frac{1}{2}}$$

$$\left(\int_{-\infty}^0 e^{2as}|w(s)|_E^2 ds\right)^{\frac{1}{2}}.$$

Since $\int_{-\infty}^{0} e^{-2as}(g(t_1 - s) - g(t_2 - s))^2 ds \to 0$ as $t_1 \to t_2$, G(t) is continuous.

Theorem (3.6). Let E be a Banach space, let A be the infinitesimal generator of a semigroup on E and let $g: [0, \infty) \to R$ satisfy

(i) $M_1^2 = \int_0^\infty [g(t)]^2 e^{2at} dt < \infty$

(ii) $g'(t)$ exists for $0 \leq t < \infty$, and

(iii) $M_2^2 = \int_0^\infty e^{2at}[g'(t)]^2 dt < \infty$.

Then the equation

$$u(t) = e^{cAt}p + \frac{1}{c}\int_{-\infty}^{t} g(t - s)u(s)ds - e^{cAt}\frac{1}{c}\left[\int_{-\infty}^{0} g(-s)u(s)ds\right] - \frac{g(0)}{c}\int_0^t e^{cA(t-s)}u(s)ds - \frac{1}{c}\int_0^t e^{cA(t-s)}\left(\int_{-\infty}^{s} g'(s - s')u(s')ds'\right)ds \tag{3.4}$$

has a unique solution on $[0, t_1]$, where $t_1 > 0$ is arbitrary.

Proof: Let $C[0, t_1; E]$ be the Banach space of continuous functions from $[0, t_1]$ to E, $0 < t_1 < \infty$ with norm

$$|u|_C = \max_{t \in [0,t_1]} |e^{-Kt}u(t)|_E$$

where K is some positive number. Define

$$(3.7)\quad [M(w, p)v](t) = e^{cAt}p + \frac{1}{c}\int_{-\infty}^{0} g(t - s)w(s)ds$$

$$+ \frac{1}{c}\int_{0}^{t} g(t - s)v(s)ds - \frac{1}{c}\, e^{cAt}\int_{-\infty}^{0} g(-s)w(s)ds$$

$$- \frac{1}{c}\int_{0}^{t} e^{cA(t-s)}\left(\int_{-\infty}^{0} g(s - s')w(s')ds'\right)ds$$

$$- \frac{1}{c}\int_{0}^{t} e^{cA(t-s)}\int_{0}^{s} g(s - s')v(s')ds'$$

$$- \frac{1}{c}\left[\int_{0}^{t} e^{cA(t-s)}v(s)ds\right]g(0).$$

It will be shown M(w, p) represents a contraction for properly chosen K.

Note that $e^{cAt}\left(p + \int_{-\infty}^{0} g(-s)w(s)ds\right)$ is continuous in t by (2.6) and $\int_{0}^{t} g(t - s)v(s)ds$ is continuous (since both g and v are continuous). By Lemma (3.5), $\frac{1}{c}\int_{-\infty}^{0} g(t - s)w(s)ds$ is continuous. For the other terms in M(w, p), continuity is shown using the theorem that $\int_{0}^{t} e^{cA(t-s)}f(s)ds$ is continuous if f is continuous [9]. Hence, M(w, p) : C[0, t; E] → C[0, t; E].

Next, we have for any v(t), r(t) in C[0, t; E]

$$\sup_{t\in[0,t_1]} |e^{-Kt}[M(w,p)v(t) - M(w,p)r(t)]$$

$$\leq \sup_{t\in[0,t_1]} e^{-Kt}\frac{1}{c}\int_0^t |g(t-s)||v(s)-r(s)|ds$$

$$+ \sup_{t\in[0,t_1]} e^{-Kt}\frac{1}{c}\int_0^t |e^{cA(t-s)}|\left(\int_0^s |g(s-s')||v(s')-r(s')|ds'\right)ds$$

$$+ \sup_{t\in[0,t_1]} e^{-Kt}\frac{1}{c}|g(0)|\int_0^t |e^{cA(t-s)}||v(s)-r(s)|ds$$

$$\leq \sup_{t\in[0,t_1]} e^{-Kt}\frac{1}{c}\int_0^t e^{Ks}e^{-Ks}|g(t-s)||v(s)-r(s)|ds$$

$$+ \sup_{t\in[0,t_1]} e^{-Kt}\frac{1}{c}\int_0^t |e^{cA(t-s)}|\left(\int_0^s |g(s-s')||v(s')-r(s')|ds'\right)ds$$

$$+ \sup_{t\in[0,t_1]} |g(0)|e^{-Kt}\frac{1}{c}\int_0^t e^{Ks}e^{-Ks}|v(s)-r(s)|ds$$

Now, by semigroup theory [10], there exists $R > 0$ and some α such that

$$|e^{cAt}|_{L(E)} \leq Re^{\alpha t} \tag{3.8}$$

for $t \geq 0$. Using this,

$$\sup_{t\in[0,t_1]} e^{-Kt}\frac{1}{c}\int_0^t e^{Ks}e^{-Ks}|g(t-s)||v(s)-r(s)|ds$$

$$+ \sup_{t\in[0,t_1]} e^{-Kt}\frac{1}{c}\int_0^t |e^{cA(t-s)}|\left(\int_0^s |g(s-s')||v(s')-r(s')|ds'\right)ds$$

$$+ \sup_{t\in[0,t_1]} |g(0)|e^{-Kt}\frac{1}{c}\int_0^t e^{Ks}|v(s)-r(s)|ds$$

$$\leq \frac{1}{c}e^{-Kt}\left(\int_0^t e^{Ks}|v-r|_c ds\right)\max_{s\in[0,t_1]}|g(s)|$$

$$+ \frac{R}{c}e^{-Kt}\int_0^t e^{\alpha s}\left(\int_0^s \text{Max}|g(s)|e^{Ks'}|v-r|_c ds'\right)ds$$

$$+ \sup_{t\in[0,t_1]} \left(|g(0)|e^{-Kt}\frac{1}{c}\int_0^t e^{Ks}|v-r|_c ds\right) \leq$$

$$\leq \left|\frac{Q}{Kc} + \frac{RQ}{cK(K - \alpha)} + |g(0)|\ \frac{1}{Kc}\right|\ |v - r|_c,$$

where $Q = \max_{s\in[0,t_1]} |g(s)|$.

Choosing K large enough to satisfy the inequality

$$\frac{Q}{c} + \frac{RQ}{c(K - \alpha)} + |g(0)|\frac{1}{c} < K,$$

M(w, p) becomes a contraction. Therefore M(w, p) has a unique fixed point. Since t_1 can be any positive number, this gives a unique solution to (3.4), for all $t > 0$.

Theorem 3.9. Let (w, p) be as in theorem (3.6). Let u(t) be the solution of (3.4) with initial value (w, p). Then $|u(t)|_E \leq C(t)|(w, p)|_{W\times E}$, where C(t) depends on t but not on (w, p).

Proof: Taking norms of both sides of (3.4) and using the triangle inequality gives

$$|u(t)|_E \leq Re^{\alpha t}|p|_E + \frac{1}{c}\int_{-\infty}^{0}|g(t - s)||w(s)|_E ds$$

$$+ \frac{1}{c}\int_0^t |g(t - s)||u(s)|_E ds + Re^{\alpha t}G(0)|w|_K$$

$$+ \frac{R}{c}\int_0^t e^{\alpha(t-s)}\left(\int_0^s |g'(s - s')||u(s')|_E ds'\right)ds$$

$$+ \frac{R\ g(0)}{c}\int_0^t e^{\alpha(t-s)}|u(s)|ds$$

$$\leq Re^{\alpha t}[|p|_E + G(0)|w|_K] + \frac{1}{c}\,G(t)$$

$$+ \frac{1}{c}\max_{s\in[0,t]}|g(s)|\int_0^t |u(s)|_E ds + \frac{R}{c}\frac{M_2}{\sqrt{2a + 2}}\int_0^t e^{\alpha(t-s')}|u(s')|_E ds'$$

$$+ \frac{R}{c}|g(0)|\int_0^t e^{\alpha(t-s')}|u(s')|_E ds.$$

Now fix t_1, $0 < t_1 < \infty$. Then on $[0, t_1]$, $e^{\alpha t} < e^{\alpha t_1}$. So using Gronwall's inequality on the inequality last obtained,

$$(3.10)\qquad |u(t_1)|_E \leq Re^{\alpha t}[|p|_E + M_1|w|_W] + \frac{1}{c}G(t_1) + \exp\left(\frac{Q}{c} + \frac{RM_2}{c\sqrt{2\alpha + 2a}} + \frac{R}{c}g(0)\right)t_1 \leq c(t)|(w, p)|_{W\times E}.$$

Now define $T(t)$ for $t \geq 0$ by

$$(3.11)\qquad T(t)(w, p) = (u_t, u(t))$$

for $t \geq 0$, where

$$u_t(s) = w(t - s) \qquad t < -s$$
$$u_t(s) = u(t - s) \qquad t > -s$$

Theorem (3.12). $T(t)$ defined by (3.11) is a strongly continuous semigroup of linear operators on $W \times E$.

Proof: For each t, $T(t)$ is linear, since equation 3.4 is linear. $T(t)$ is bounded by Theorem (3.9). $T(t)(w, p)$ is continuous in t by (3.9).

So only (2.5) must be checked. Let $w \in W$, $p \in E$, then

$$u(t_1 + t_2) = e^{cA(t_1+t_2)}p + \frac{1}{c}\int_{-\infty}^{t_1+t_2} g(t_1 + t_2 - s)u(s)ds$$
$$- \frac{1}{c}e^{cA(t_1+t_2-s)}\int_{-\infty}^{0} g(-s)u(s)ds$$
$$- \frac{1}{c}\int_0^t e^{cA(t-s)}\left(\int_{-\infty}^{s} g'(s - s')u(s')ds'\right)ds$$
$$- \frac{1}{c}g(0)\int_0^{t_1+t_2} e^{cA(t_1+t_2-s)}u(s)ds \quad =$$

$$= e^{cAt_1}(e^{cAt_2}p + \frac{1}{c}\int_{-\infty}^{t_2} g(t_2 - s)u(s)ds$$

$$- \frac{1}{c} e^{cA(t_2-s)} \int_{-\infty}^{0} g(-s)u(s)ds$$

$$-\frac{1}{c}\int_{0}^{t_2} e^{cA(t_2-s)} (\int_{-\infty}^{s} g'(s - s')u(s')ds')ds$$

$$- \frac{1}{c}\int_{t_2}^{t_1+t_2} e^{cA(t_1+t_2-s)} (\int_{-\infty}^{s} g'(s - s')u(s')ds')ds$$

$$- \frac{g(0)}{c}\int_{t_2}^{t_1+t_2} e^{cA(t_1+t_2-s)} u(s)ds - e^{cAt_1}\frac{1}{c}\int_{-\infty}^{t_2} g(t_2 - s)u(s)ds$$

$$= e^{cAt_1}u(t_2) + \frac{1}{c}\int_{-\infty}^{t_1} g(t_1 - s)u_{t_2}(s)ds$$

$$- \frac{1}{c} e^{cAt_1} \int_{-\infty}^{0} g(-s)u_{t_2}(s)ds$$

$$- \frac{1}{c}\int_{0}^{t_1} e^{cAt_1-s)} (\int_{-\infty}^{s} g'(s - s')u_{t_2}(s')ds')ds$$

$$- \frac{1}{c} (\int_{0}^{t_1} e^{cA(t_1-s)} u_{t_2}(s)ds)g(0)$$

after making the change of variables $-t_2 + s \to s$, and $-t_2 + s' \to s'$.

So (2.5) is satisfied, and T(t) is a semigroup.

4. THE INFINITESIMAL GENERATOR

Now the infinitesimal generator of T(t) will be found.

Theorem 4.1. Let T(t) be the semigroup given in Theorem (3.12). Then the infinitesimal generator of T(t) is

$$A(w, p) = (w, A(cp - \int_{-\infty}^{0} g(-s)w(s)ds)) \tag{4.2}$$

where the domain of A, represented by D(A), is given by

(4.3) $$D(A) = \{(w, p): w \text{ and } \dot{w} \in W,\ p \in E,\ \lim_{t\to 0^-} w(t) = p,$$

$$\text{and } (cp - \int_{-\infty}^{0} g(-s)w(s)ds) \in D(A)\}.$$

Here $\dot{w}(t)$ is the "weak" derivative of w [11].

Proof: Let A(w, p) be the infinitesimal generator of T(t). Then for $(w, p) \in D(A)$,

(4.4) $$A(w, p) = \lim_{t\to 0} \frac{T(t)(w,p) - (w,p)}{t} = \lim_{t\to 0}\left(\frac{u_t - w}{t}, \frac{u(t) - p}{t}\right)$$

By definition, $\lim_{t\to 0} \frac{w_t - w}{t} = \dot{w}$, where $\dot{w}$ is the weak derivative of w [11]. For $\dot{w}$ to exist, $\lim_{t\to 0} w(t)$ must exist [11].

Since

$$\lim_{t\to 0^+} u(t) = \lim_{t\to 0^+}\Big[e^{cAt}p + \frac{1}{c}\int_{-\infty}^{t} g(t - s)u(s)ds$$

$$- \frac{1}{c} e^{cAt}\int_{-\infty}^{0} g(-s)u(s)ds - \frac{1}{c}\Big(\int_{0}^{t} e^{cA(t-s)}u(s)ds\Big)g(s)$$

$$- \frac{1}{c}\int_{0}^{t} e^{cA(t-s)}\Big(\int_{-\infty}^{s} g'(s - s')u(s')ds'\Big)ds\Big] = p,$$

$$\lim_{t\to 0} u(t) = \lim_{t\to 0} w(t) = p.$$

For the second component of $\frac{1}{t}(T(t)(w, p) - (w, p))$

(4.5) $$\frac{1}{t}(u(t) - p) = [e^{cAt}[p - \frac{1}{c}\int_{-\infty}^{0} g(-s)w(s)ds]$$

$$- (p - \frac{1}{c}\int_{-\infty}^{0} g(t - s)w(s)ds) + \frac{1}{c}\int_{-\infty}^{0} g(t - s)w(s)ds \ +$$

$$+ \frac{1}{c}\int_0^t g(t-s)u(s)ds - \frac{1}{c}\left(\int_0^t e^{cA(t-s)}u(s)ds\right)g(0)$$

$$- \frac{1}{c}\int_0^t e^{cA(t-s)}\left(\int_{-\infty}^0 g'(s-s')w(s')ds'\right)ds$$

$$- \frac{1}{c}\int_0^t e^{cA(t-s)}\left(\int_0^s g'(s-s')w(s')ds'\right)ds\Big]\frac{1}{t}$$

$$= \frac{1}{t}\Big[e^{cA(t-s)}\left(p - \frac{1}{c}\int_{-\infty}^0 g(-s)w(s)ds\right)$$

$$- \left(p - \frac{1}{c}\int_{-\infty}^0 g(-s)w(s)ds\right]$$

$$+ \frac{1}{ct}\left(\int_{-\infty}^0 [g(t-s) - g(-s)]w(s)ds\right.$$

$$- \frac{1}{c}\int_0^t e^{cA(t-s)}\left(\int_{-\infty}^0 g'(s-s')w(s')ds'\right)$$

$$+ \frac{1}{c}\Big[\int_0^t (g(t-s) - g(0))u(s)ds\Big]\frac{1}{t}$$

$$+ \frac{1}{c}\left(\int_0^t [1 - e^{cA(t-s)}]g(0)pds\right)\frac{1}{t}$$

$$+ \frac{1}{c}\Big[\int_0^t e^{cA(t-s)}g(0)[p - u(s)]ds\Big]\frac{1}{t}$$

$$- \frac{1}{c}\Big[\int_0^t e^{cA(t-s)}\left(\int_0^s g'(s-s')u(s')ds'\right)ds\Big]\frac{1}{t}$$

We will "catalog" these terms in the following way:

(i) $\frac{1}{t}\left(e^{cAt}\left(p - \frac{1}{c}\int_{-\infty}^0 g(-s)w(s)ds\right) - \left(p - \frac{1}{c}\int_{-\infty}^0 g(-s)w(s)ds\right)\right)$

(ii) $\frac{1}{ct}\left(\int_{-\infty}^0 [g(t-s) - g(-s)]w(s)ds\right.$
$\left. - \frac{1}{c}\int_0^t e^{cA(t-s)}\left(\int_{-\infty}^0 g'(s-s')w(s')ds'\right)ds\right)$

(iii) $\frac{1}{ct}\left[\int_0^t (g(t-s) - g(0))u(s)ds\right]$

(iv) $\frac{1}{ct}\int_0^t [1 - e^{cA(t-s)}]g(0)pds$

(v) $\frac{1}{ct}\int_0^t e^{cA(t-s)}g(0)[p - u(s)]ds$

(vi) $\frac{1}{ct}\left[\int_0^t e^{cA(t-s)}\left(\int_0^s g'(s-s')u(s')ds'\right)ds\right]$

Each of these terms will be considered separately.

Since g is continuous (iii) goes to zero. The inequality (2.6) and the continuity of u(t) shows (v) goes to zero.

For term (vi),

$$\frac{1}{ct}\left(\int_0^t [1- e^{cA(t-s)}]pds\right)g(0)$$

$$= \frac{1}{t}\cdot\frac{1}{c}\,g(0)\int_0^t (1 - e^{cAs})pds$$

$$\leq \frac{1}{t}\cdot c\cdot g(0)\cdot t \sup_{0\leq s\leq t} |e^{cAs}p - p|.$$

Since $e^{cAs}p$ is a continuous function of s, this goes to zero.

For the term (vi)

$$\frac{1}{ct}\left[\int_0^t e^{cA(t-s)}\left(\int_0^s g'(s-s')u(s')ds'\right)\right]$$

$$\leq \frac{1}{c}\,Re^{\alpha t}\int_0^t |g'(t-s')||u(s')|ds'$$

which goes to zero as $t \to 0$.

Now, for term (ii),

$$\frac{1}{c}\int_{-\infty}^{0}[g(t-s)-g(-s)]w(s)ds$$

$$-\frac{1}{c}\int_{0}^{t}e^{cA(t-s)}\left(\int_{-\infty}^{0}g'(s-s')w(s')ds'\right)ds\,\frac{1}{t}$$

$$=\frac{1}{c}\int_{-\infty}^{0}[g(t-s)-g(-s)]\frac{1}{t}w(s)ds-\frac{1}{c}\int_{-\infty}^{0}g'(-s')w(s')ds'$$

$$-\frac{1}{c}\int_{0}^{t}\int_{-\infty}^{0}(g'(s-s')-g(-s'))w(s')ds'ds\frac{1}{t}$$

$$-\frac{1}{c}\int_{0}^{t}(e^{cA(t-s)}-1)\left(\int_{-\infty}^{0}g'(s-s')w(s')ds'\right)ds$$

$$=\frac{1}{c}\int_{-\infty}^{0}[g(t-s)-g(-s)]\frac{1}{t}w(s)ds-\frac{1}{c}\int_{-\infty}^{0}g'(-s')w(s')ds'$$

$$-\frac{1}{ct}\int_{0}^{t}(G(s)-G(0))ds-\frac{1}{ct}\int_{0}^{t}(e^{cA(t-s)}-1)G(s)ds.$$

Now,

$$\lim_{t\to 0}\frac{1}{c}\int_{-\infty}^{0}\frac{g(t-s)-g(-s)}{t}w(s)ds=\frac{1}{c}\int_{-\infty}^{0}g'(-s)w(s)ds$$

so

$$\lim_{t\to 0}\frac{1}{c}\int_{-\infty}^{0}\frac{g(t-s)-g(-s)}{t}w(s)ds-\frac{1}{c}\int_{-\infty}^{0}g'(-s)w(s)ds=0.$$

Also

$$\lim_{t\to 0}\frac{1}{ct}\int_{0}^{t}(G(s)-G(0))ds=0$$

and

$$\lim_{t\to 0}\frac{1}{ct}\int_{0}^{t}(e^{cA(t-s)}-1)G(s)ds=0,$$

since G is continuous. Therefore

$$\lim_{t\to 0} \frac{u_t - p}{t} = \lim_{t\to 0} \left(e^{cAt}\left[p - \frac{1}{c}\int_{-\infty}^{0} g(-s)w(s)ds\right] - p - \frac{1}{c}\int_{-\infty}^{0} g(-s)u(s)ds\right)\frac{1}{t} \tag{4.5}$$

and the existence of either limit implies the existence of the other. By semigroup theory [10], the right hand side equals

$$A\left(cp - \int_{-\infty}^{0} g(-s)w(s)ds\right)$$

and so $(w, p) \in D(A)$ if and only if w and $\dot{w} \in K$, $\lim_{t\to 0} w(t) = p$, and

$$cp - \int_{-\infty}^{0} g(-s)w(s)ds \in D(A).$$

In this case

$$A(w, p) = \left(w, A\left(cp - \int_{-\infty}^{0} w(s)g(-s)ds\right)\right). \tag{4.6}$$

The next theorem will exhibit the spectrum of A.

First, a few definitions are needed [12]. Let E be a Banach space. Let V be a linear, not necessarily continuous operator on E. Let $R(\lambda, V) = (V - \lambda I)^{-1}$, where λ is a complex number.

Let

$$\rho(V) = \{\lambda \in C : R(\lambda, V) \text{ exists, is continuous, and has domain } E\}$$

and let

$\sigma(V)$ = complement of $\rho(V)$ in C.

$\sigma(V)$ is divided into three subsets.

$P\sigma(V) = \{\lambda \in C \mid R(\lambda, V) \text{ does not exist}\}$

$C\sigma(V) = \{\lambda \in C \mid R(\lambda, V)$ exists with dense domain, but is not continuous$\}$

$R\sigma(V) = \{\lambda \in C \mid R(\lambda, V)$ exists, but its domain is not dense$\}$

$\rho(V)$ is called the resolvent of V, $\sigma(V)$ the spectrum of V and $P\sigma(V)$, $C\sigma(V)$ and $R\sigma(V)$ the point, continuous, and residual spectrum of V respectively.

Theorem 4.7. Let A be the operator in (4.1). Let

$$M_\lambda u(t) = \int_0^t e^{\lambda(t-s)} u(s)ds \tag{4.8}$$

$$\tilde{g}(t) = \int_0^\infty e^{-\lambda s} g(s)ds \tag{4.9}$$

$$\mu(\lambda) = \frac{\lambda}{c - \tilde{g}(\lambda)} \tag{4.10}$$

$$J_\lambda = R(\lambda, A)A \tag{4.11}$$

$$p(v, u, \lambda) = \frac{\mu(\lambda)}{\lambda} R(\mu(\lambda), A)v + \frac{\mu}{\lambda} \int_{-\infty}^0 g(-s)M_\lambda J_\lambda u(s)ds \tag{4.12}$$

where $v \in E$, $u \in W$. Let

$$\sigma_1 = \{\lambda \mid \text{Re } \lambda \leq -a\}$$

$$\sigma_2 = \{\lambda \mid \mu(\lambda) \in \sigma(A)\}$$

$$\sigma_3 = \{\lambda \mid c - \tilde{g}(\lambda) = 0\}.$$

Then

$$\sigma(A) = \sigma_1 \cup \sigma_2 \cup \sigma_3. \tag{4.13}$$

Furthermore, if $c - \tilde{g}(\lambda_1) = 0$, and $\lambda_1 \neq 0$, then $\lambda_1 \in C\sigma(A)$, where $C\sigma(A)$ represents the continuous spectrum of A.

If $c - \tilde{g}(0) = 0$, then 0 is an eigenvalue with an infinite dimensional null space (if E is infinite dimensional). Also, if $\lambda \in \rho(A)$, then

$$(4.14) \quad R(\lambda, A)(v, u) = (M_\lambda u + e^{\lambda t}p(\lambda, u, v), p(\lambda, u, v)).$$

Proof: First, $\tilde{g}(\lambda)$ exists for $Re(\lambda) > -a$ and

$$|\int_0^\infty e^{-\lambda s}g(s)ds| \leq (\int_0^\infty e^{(-Re\lambda - a)2s}ds)^{\frac{1}{2}}$$

$$\cdot \left| \int_0^\infty e^{2as}g^2(s)ds\right|^{\frac{1}{2}} \leq \frac{1}{\sqrt{Re\lambda + a}} \cdot |g|.$$

Now, suppose $(A - \lambda I)(w, p) = (u, v)$. Then $w - \lambda w = u$. So

$$w = \int_0^t e^{\lambda(t-s)}u(s)ds + e^{\lambda t}p$$

since $\lim_{t\to 0} w(t) = 0$. Substituting this for w in the equation gives

$$cAp - \int_{-\infty}^0 g(-s)(\int_0^s e^{\lambda(s-s')}Au(s')ds')ds$$

$$- (\int_0^\infty e^{-\lambda s}g(s)ds)Ap - \lambda p = v.$$

So

$$[c - \tilde{g}(\lambda)]Ap - \lambda p = v + \int_{-\infty}^0 g(-s)M_\lambda Au)(s)ds.$$

If $c - \tilde{g}(\lambda) \neq 0$, dividing by $c - \tilde{g}(\lambda)$ gives

$$Ap - \frac{\lambda}{c - \tilde{g}(\lambda)} p = \frac{v}{c - \tilde{g}(\lambda)} + \frac{1}{c - \tilde{g}(\lambda)} \int_{-\infty}^{0} g(-s)(M_\lambda Au)(s)ds$$

If $\frac{\lambda}{c - \tilde{g}(\lambda)} = \mu(\lambda) \in \rho(A)$, then

$$p = (R(\mu, A)v)\frac{\mu}{\lambda} + \frac{\mu}{\lambda} \int_{-\infty}^{0} g(-s)M_\lambda(R(\mu(\lambda), A)Au)(s)ds.$$

If $\frac{\lambda}{c - \tilde{g}(\lambda)} \in \sigma(A)$, then p will not be a continuous function of (u, v), where $(u, v) \in W \times E$. Also, if $Re(\lambda) \leq -a$, M_λ is not a bounded linear operator, so again $\lambda \in \sigma(A)$.

If $c - \tilde{g}(\lambda) = 0$, then the equation for p becomes

$$-\lambda p = v + \int_{-\infty}^{0} g(-s)(M_\lambda Au)(s)ds.$$

So, if $\lambda \neq 0$,

$$p = -\frac{v}{\lambda} - \frac{1}{\lambda} \int_{-\infty}^{0} g(-s)(M_\lambda Au)(s)ds$$

$$= -\frac{v}{\lambda} - \frac{1}{\lambda} A \int_{-\infty}^{0} g(-s)(M_\lambda u)(s)ds.$$

Since A is an infinitesimal generator, its domain is dense. So $R(\lambda, A)$ is defined here with dense domain, but is not continuous. So $\lambda \in C\sigma(A)$, the continuous spectrum of A.

If $\lambda = 0$, and $c - \tilde{g}(0) = 0$, then (p, p) is an eigenvector, for any $p \in D(A)$.

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ANIMAL INTERACTIONS

by R.E. Blackwelder and W.G. Dyer
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Carbondale

No animals live without contacts of some sort with other animals. Contacts between two animals may be by chance crossing of paths, or for cooperation in mutual purposes, or in competition to fill some need, or for exploitation of one by the other. Most animals have contacts of some sort with a considerable variety of others, as predator, as prey, as mate, as offspring, for competition for space and shelter and food, or for some of a wide variety of other purposes.

In contemplating these interactions, it has been possible to group them under certain words, such as symbiosis, commensalism, parasitism, predation, reproduction, and so on. The animals show so many variations and combinations of these that the words have come to have somewhat indefinite and varying meanings. There has seemed to be confusion over the relations involved, although this is surely due principally to the inadequacy of the terms.

An unrestricted tabulation of the associations or interactions between any two animals shows these to be far more diverse than is usually made clear. Most animals have associations of many sorts, both with their own kind and with other kinds, and for the most part these relations are of similar sort within the species and between species. We have therefore intentionally left the matter wide open, treating all associations of any two animals without initial regard to whether they are of one species, two related species, or species in separate phyla. The possibility of producing complexity or confusion by this broad approach seems to have been escaped, and in any case it is overridden by the advantages of seeing the total picture of animal relationships.

Animal associations could be classified on any of these aspects:

1) Genetic relationship (of same species, of different species, or of different groups)
2) Purpose (accidental, cooperative, competitive, or exploitative)
3) Product or result of the inter-action (reproduction, food, space, shelter, labor, transport, construction)
4) Stage of life cycle (of either animal)
5) Who is benefited
6) Duration (momentary, temporary, permanent)
7) Intent or choice (chance meeting, planned meeting, automatic position)
8) Specificity (random animals, always same species, always same two species, one of a variety of species)
9) Fatality (death of one inevitable, severe damage possible, slight damage, no measurable damage)
10) Others

What makes tabulation necessary is that associations occur in a variety of combinations of these aspects. In these multiple-aspect cases (especially in exploitation) the importance of the different aspects also varies widely, greatly increasing the diversity in associations. The resulting associations defy classification, because intermediate examples are almost always found if sufficient search is made. The diversity of relationship is a reflection of the diversity of the animals, in which behavior is an important aspect. The way of life of a lion, a leaf-mining insect, a tapeworm, a colonial bryozoan, a jellyfish, and an amoeba are diverse, but when some of the relatives of these live in competition and exploitation with their own and other kinds, the diversity of behavior is many times multiplied.

The accompanying table is really two tables in one, first for the cases where the two animals belong to one species and second for the cases where they belong to different (usually widely different) species. These two are combined to show both the similarities in the two lists and the differences between them. Annotations and examples are used for amplification.

This tabulation does not bear out our initial expectation that the great diversity in animal interactions would make it impossible to use clearly the customary words. The only well-known word which finds no place in this chart is symbiosis, which by its inherent meaning (living together) should be used to cover all cooperation between and all exploitation of actual animals of different species. For the rest, the usual terms in reasonably restricted meanings find logical places in the diagram (different species). A few varieties of interaction are not covered by any of the usual terms, and many are covered only by the most general one (symbiosis).

There is sometimes a temptation to supply new terms for ideas or situations not covered by old ones in such an analysis. We think this would be futile, because even these do not cover all the possible interactions, and the diversity of animal behavior will defy all regimentation in such a set of terms.

Most biologists restrict all these terms to interactions between individuals of different species (the right-hand column). In this treatment the following would be the major types:

Mutualism, which is actually mutual exploitation
Competition, for shelter, food, or territory
Exploitation, among which are included:
For food:
Predation
Micropredation
Ectoparasitism
Endoparasitism
Commensalism
For transport:
Phoresy
Domestication
For other purposes:
Domestication
(others without specific terms)

The word parasitism should logically be restricted to ecto- and endoparasitism, as exemplified in ticks and tapeworms, respectively. The use of the word parasitism in entomology, however, is well established for a quite different situation. In an effort to avoid this difficulty, some entomologists have switched to the term parasitoidism for the "parasitic" insects such as Hymenoptera. This still hides the real nature of the relationship, which is that of a predator on the early stages of the life history, not that of a parasite (either ecto or endo-). Micropredation is exactly correct for this situation and is therefore preferable to either of the others in those insects which do kill their "hosts" (prey).

The purpose of this paper is to point up the diversity of animal interactions and the inadequacy of the existing definitions to group them. Further terms will not cure the inadequacy, but an understanding of the existing diversity of interactions would help to prevent inadequate communication caused by understatement of the diversity and oversimplification of the relationships.

All Associations

ACCIDENTAL (passive)

same species	different species
Aggregations (usually in competition)	(Apparently all can be called Purposeful, as competition for space, at least, is always involved)
Colonies (Bryozoa, corals)	

PURPOSEFUL

same species	different species
Cooperation	**Cooperation**
Bisexual reproduction Societies Colonial division of labor (reproduction, feeding, protection, locomotion) Grooming	Mutualism (= mutual exploitation)
Competition	**Competition**
Shelter, food, territory, mate	Shelter, food, territory
Exploitation	**Exploitation**
For food Normally fatal Cannibalism	For food (all metabolic needs) Normally fatal Predation Predator/prey (carnivores) Micropredation Embryonic predator, in egg, larva, or adult (wasps, flies)
Normally not fatal individually Transferring digested food — — —	Normally not fatal individually
Secretions (milk)	Ectoparasitism Occasional blood-sucking visitor (mosquito) On surface; hair, scales, feathers, skin, exudations (lice, mites)
Endoparasitism	Endoparasitism In surface tissues; follicles, gills (chiggers, glochidia) In ectodermal passages (tongue worms) In digestive tract lumen (tapeworms) In internal tissues or organs (eye worms, sporocysts) In body cavity (larval tapeworms)
From tissues (egg yolk)	

In particular organs (endoparasitic males, human foetus)	In particular organ lumen; gonad, lung, bladder (giant kidney worms) In vessels or ducts (trypanosomes, flukes, nematodes)
— — —	Commensalism In faeces, internally (protozoans) Outside, for stolen or lost food (pilot fish, jackal)
For shelter (all physical needs) On parent (opossum young) In host (endoparasitic males) In parent's shelter (house, den, tube) In parent's ''shadow'' (parental protection)	For shelter On host (barnacle on whale) In host (fish in sea cucumber cloaca) In living host's shelter (worm tubes) In host's ''shadow'' (a fish living among the tentacles of *Physalia)*
For care of non-feeding polymorphs (colonies)	— — —
For use of labor	For use of labor
For use of labor Slavery Digestion of food (fed to young) Care of young	For use of labor Slavery, domestication Digestion of food (by intestinal biota) Care of young (slave ants, cuckoos)
— — —	For camouflage (sponge on snail shell)
For transport (Mammal carrying young)	For transport: Phoresy To another host; to food source, to another site (phoretic insects, man on horseback)
For use of constructions Abandoned nests & dens Re-use of zooecium	For use of constructions Abandoned nests & dens Hermit crab in shell
For control by social hormones (termites)	— — —
For control of caste by feeding (ants, termites)	— — —
For use of transplanted organs (Crustacea, man)	For use of transplanted nematocysts (flatworms, ctenophores, nemerteans)
For man's purposes Esthetics, experimentation, sport, commerce, religious sacrifice	For man's purposes Esthetics, experimentation, sport, commerce, religious sacrifice, medicine

MULTIPLE ASSOCIATIONS

(Always divisible into pairs and therefore treatable above)

Occurence of *Argulus* (Crustacea: Branchiura) on the White Crappie, *Pomoxis annularis* Rafinesque, and Free-swimming in the Southern Illinois Reservoirs

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ABSTRACT

A total of ten specimens of Argulus *were collected from two man-made southern Illinois reservoirs. Five specimens of* A. appendiculosus *Wilson and four specimens of* A. stizostethi *Kellicott were collected by meter net tows from Crab Orchard Lake, Williamson Co. and Rend Lake, Franklin Co. One specimen of* A. stizostethi *was collected from a white crappie,* Pomoxis annularis *Rafinesque, from Crab Orchard Lake. This is the first reported occurence of* A. stizostethi *from white crappie and the first reported occurrence in Illinois.*

INTRODUCTION

Argulus spp., or fish lice, are ectoparasites of fishes. They attach by means of spines and suckers and feed upon host tissue. Mortality of fish has been attributed to these parasites, Schumacher (1952). Although the systematics of the genus were extensively investigated (Wilson, 1903; Meehean, 1940; Hoffman, 1970; and Cressey, 1972), few studies have been conducted in the lower midwest and apparently none from southern Illinois.

During the spring, summer, and fall of 1979 argulid populations of three southern Illinois reservoirs were monitored by meter net tows and by examination of white crappie, *Pomoxis annularis* Rafinesque. During these samplings several specimens of free-swimming and one specimen of attached *Argulus* were collected.

MATERIALS AND METHODS

Between May and December 1979, meter net tows were employed to sample free-swimming argulids while white crappie obtained by use of trap nets were examined for occurrence of argulids. Sampling was conducted biweekly between May and August and monthly otherwise. The lakes sampled were: Crab Orchard Lake, Williamson Co.; Lake of Egypt, Williamson Co.; and Rend Lake, Franklin Co. Three meter tows (mesh = 10/cm.) of one to three mintues in duration were taken just below the water surface at dusk. All argulids collected were immediately fixed in 10% formalin and subsequently sorted by species and preserved in 70% ethanol. Four trap nets were set each evening and removed the following morning. A total of 285, 189, and 220 white crappie were collected from Crab Orchard Lake, Lake of Egypt, and Rend Lake, respectively. Crappie were place in plastic bags on ice in a cooler and transported to the laboratory for examination.

RESULTS AND DISCUSSION

Two species of Argulus were collected from southern Illinois reservoirs, *A. appendiculosus* Wilson from Rend Lake and *A. stizostethi* Kellicott from Crab Orchard Lake and Rend Lake. This appears to be the first reported occurence of *A. stizostethi* from white crappie and the first reported occurrence of the species in Illinois.

A total of nine free-swimming argulids were collected by meter net tows. Five specimens of *A. appendiculosus* were collected from Rend Lake, two on 18 June, two on 28 June, and one on 24 September. Four specimens of *A. stizostethi* were collected, two on 18 June and one on 28 June from Rend Lake and one on 10 June from Crab Orchard Lake. All free-swimming argulids were collected in June or September, no specimens were collected during the spring, mid summer, and late fall. Tidd (1929) observed similar seasonal trends in abundance for *Argulus* collected by meter net tows from Lake Erie. Wilson (1903) observed argulids to exhibit multiple breeding periods in early summer, late summer, and early fall. Since argulids usually detach from their fish hosts to breed, it is quite likely specimens collected from meter net tows had recently detached from their host in order to breed.

A single specimen of *A. stizostethi* was observed from the white crappie. The specimen was collected from just below the left pectoral fin of a female white crappie (TL = 200 mm., Wt. = 95.4 g., K = 2.46) captured from Crab Orchard Lake on 14 August.

Length and width measurements were conducted for all collected argulids. *A. stizostethi* ranged from 4.2 mm. to 6.2 mm. in length and 2.0 mm to 3.0 mm. in width with an average length and width of 5.1 mm. and 2.4 mm., respectively. *A. appendiculosus* ranged from 3.8 mm. to 7.0 mm. in length and 3.0 mm. to 6.0 mm. in width with an average length and width of 5.0 mm. and 4.1 mm., respectively. Wilson (1903) observed lengths and widths for *A. stizostethi* to average 6.6 mm. and 3.1 mm., respectivley. Meehean (1940) reported lengths to 8.5 mm. and 12.0 mm. for *A. Stizostyethi* and to 10 mm. for *A. appendiculosus*. In general, argulid specimens collected during this investigation are somewhat smaller than those reported in literature.

Two specimens of *A. appendiculosus* (catalogue numbers 91 A.0 and 92 A.0) and two specimens of *A. stizostethi* (catalogue number 93 A.0) are stored in the parasitological collection of the zoological research museum at Southern Illinois University-Carbondale. The remaining specimens have been retained in the personal collection of the author.

ACKNOWLEDGEMENTS

I would like to thank Dr. R. Cressey of the Smithsonian Institution for examining and confirming the identified specimens and the Cooperative Fisheries Research Laboratory at Southern Illinois University-Carbondale, especially Dr. R. C. Heidinger and Dr. W. M. Lewis, for assistance provided.

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Table 1. *Argulus* collection information, 1979.

Species	(N)[1]	Capture date	Capture site	Host
A. appendiculosus	(2)	18 June	Rend Lake	Meter net tow
	(2)	28 June	Rend Lake	Meter net tow
	(1)	24 Sept.	Rend Lake	Meter net tow
A. stizostethi	(1)	10 June	Crab Orchard Lake	Meter net tow
	(2)	18 June	Rend Lake	Meter net tow
	(1)	28 June	Rend Lake	Meter net tow
	(1)	14 Aug.	Crab Orchard Lake	White crappie

[1] N = number of specimens collected.

First Reported Occurrence of *Argulus mississippiensis* (Crustacea: Branchiura) from Illinois

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ABSTRACT

Argulus mississippiensis *Wilson was collected from longnose gar,* Lepisosteus osseus *(Linnaeus), captured from Lake Carlyle, Clinton Co. This is the first reported occurrence of* A. mississippiensis *in Illinois.*

On 14 September 1977 a single specimen of *Argulus mississippiensis* Wilson was collected from a longnose gar, *Lepisosteus osseus* (Linnaeus), captured from Lake Carlyle, Clinton Co. A review of literature and personal communication with Dr. R. Cressey of the Smithsonian Institution indicated the known range of *A. mississippiensis* to include Indiana and Iowa, but not Illinois. This report constitutes a range extension and is the first for *A. mississippiensis* from Illinois.

The specimen is deposited as catalogue number 90 A.0 in the Parasitological Collection of the Zoological Research Museum at Southern Illinois University-Carbondale.

In addition to being reported from Indiana and Iowa, *A. mississippiensis* has also been reported from Louisiana, Hoffman (1970) and Cressey (1972). The argulid has only been collected from gar, *Lepisosteus sp.*

LITERATURE CITED

CRESSEY, R.F. 1972. Biota of Freshwater Ecosystems. Identification manual No. 2, The Genus *Argulus* (Crustacea: Branchiura) of the United States. U.S. Govt. Doc. EP 1.15:18050 Eld 02/72/40.2.

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Rollo T. Rexroat
(1893-1979)
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Rollo T. Rexroat a noted collector of west-central Illinois vascular plants from Virginia, Illinois died November 16, 1979 in Jacksonville, Illinois at the age of 86. He was born in Cass County near Virginia, January 6, 1893 and was a lifelong resident of the area. He was a veteran of World War I. He owned and operated Rexroats' general store, the oldest around the Virginia town square, and could be found working there daily.

West-Central Illinois has been fortunate in having some prominent vascular plant collectors who have not been professional botanists by training but as a result of their hobby became very knowledgeable people about the flora and whose knowledge and contributions often rivaled the professionals. Mr. Rexroat joins the list which includes S. B. Mead (1799-1880) a Hancock County physician, F. Brendel (1820-1912) a Peoria County physician, H.W. Patterson (1853-1919) a Henderson County printer and V.H. Chase (1876-1966) a Peoria County railroader. Mr. Rexroat collected most actively from 1953 to 1965 principally in Cass and Mason Counties but also with numerous collections from, but not limited to Morgan, Scott, Greene, Calhoun, Pike, Adams, Brown, Schuyler and McDonough Counties.

Upon entering and looking around Mr. Rexroat's store it is immediately evident by the hornet's

nest, duck decoys, stuffed birds, dried plant boquets, guns, Indian relics, etc. that he was an avid outdoorsman and collector. He would go to the field once or twice a week in the afternoons when he could get away from the store as well as on Sundays. Although he originally learned and collected plants on hunting trips he later made special trips for botanizing. He estimated he drove about 40,000 miles and walked 50,000 miles (Winterringer, 1965). Sometimes his wife, Irene,would drive the car while he would scrutinize the roadside for plants ordering her to stop when appropriate. With his large friendly smile, battered hat, hand-made six foot long hickory cane to pull down unreachable tree branches and back-pack with field press, he would embark on his forays. He made his own presses of two types. One was a light field type which held about forty plants to carry in his back-pack (which was patterened after a World War I pack which he used orginially but found unsatisfactory in part due to a draw-string top) along with gloves, plastic bags (he did not use a vasculum since it ''was in the way''), insect repellent and notebook. The other press, which was heavier and held about fifty plants, was kept in the car where he transferred to it his field pressed plants. He dried his plants over an oil stove in his store in the fall and early spring and the rest of the year over light bulbs in an old porcelain refrigerator with the top removed. Although he did not use identification keys he was proficient in using the illustrations in Britton and Brown's Illustrated Flora of Northeastern United States and Adjacent Canada and eventually could go directly to the family in the book. He could be found working with his plants in the rear of his store on a counter over which was suspended an unshaded light bulb. He meticuously recorded a diligent and accurate record of his collection data for each plant both on a slip of paper inserted with each pressed plant and also in a master record book. He recorded his finds an annotations in his copy of Jones and Fuller's Vascular Plants of Illinois and Jones' Flora of Illinois. His notes sometimes contained his own descriptive common name of a plant to remind him of it appearance as for example low beggars lice for *Circaea latifolia* Hill, Indian war club for *Carex grayii* Carey and coontail grass for *Echinochloa walteri* (Pursh) Heller. He routinely took his plants to the Illinois State Museum Herbarium (ISM) at Springfield where his identifications were verified or problem plants identified. He donated a set of his plants, which numbered about 11,000 specimens; to the Museum Herbarium. After his death his wife donated to the R.M. Myers Herbarium of Western Illinois University (MWI) his duplicate personal collection of about 8000 unmounted specimens which have been designated the R.T. Rexroat Collection. His collections include hundreds of county records, 18 state records, 20 species which had not been seen in Illinois for nearly a century and 40 more species which are infrequently collected (Dolbeare, 1973). Mr. Rexroat's conservation ethic was evident in that he would transplant plants that were to be destroyed by construction, pasturing, etc. but would always leave some plants never to take the last one.

Dolbeare (1973) and Winterringer (1965) have published biographical information (including a photograph) about Mr. Rexroat. The scientific importance of his collections has been noted by Dolbeare (1973) and Winterringer (1963,1965). A summary, with bibliography, of Mr. Rexroats state and county records as well as a list of his previously unreported fern and monocot plant county records has been compiled by Dolbeare (1973). Winterringer's (1965) apt statement ''R.T. Rexroat is an excellent example of what the layman may contribute to science'' is exemplified as students use his invaluable collections in their studies contributing to the knowledge of the States' vascular plant flora. A few acres of prairie in the Jenny Marr Dunaway Park at the southern edge of Virginia, Illinois was dedicated in his honor as the Rexroat Prairie.

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VARIATIONS IN THE PHYTOPLANKTON OF A NEWLY FORMED RESERVOIR

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ABSTRACT

The phytoplankton of a newly formed reservoir has been studied with respect to composition and component variation as a function of reservoir age. Collections were made from 7 stations in the northern portion of Cedar Creek Reservoir, Jackson County, Illinois over a one year period beginning in February 1974. The study area included approximately one-fifth of the 709 hectare, 6.12 x 10^7 m^3 lake. Ninety-eight algal taxa representing 6 divisions were identified. An overall increase in species and total cell densities was observed during the period of investigation. Motile forms were dominant at the beginning of the study period. Cyanophytes and chrysophytes were responsible for two large pulses which occurred in early summer 1974 and in mid-winter 1975. It appears that Cedar Creek Reservoir is becoming moderately eutrophic.

INTRODUCTION

Although much work has been done on established bodies of water, a scan of the literature reveals few works which deal with the phytoplankton of newly impounded reservoirs. Investigations which have been done, deal primarily with considerations other than floral composition.

The objective of this study was two fold: first to provide a list of the algae found in Cedar Creek Reservoir through an annual cycle shortly after impoundment and second to examine the changes in the phytoplankton which occurred during this time. Collection began 6 months after impoundment, at which time the pool had reached approximately 50% of its final volume, and continued for a period of one year. Therefore, this study provides a record of the phytoplankton composition and variations over the first year of existance, beginning in early spring.

It is hoped that information gained in this study will provide a foundation upon which future comparative studies can be based.

SITE DESCRIPTION

The study area included the northern fifth of Cedar Creek Reservoir in Jackson County, Illinois. The reservoir has a surface area of 709 ha and a volume of 6.12 x 10^7 m^3. It has a maximum depth of 14 m which occurs near the saddle dam (Fig. 1). Construction of Cedar Creek Reservoir began in spring 1972; completion and resulting impoundment occurred in August 1973. The lake reached spillway level in fall 1974. A significant portion of the study area is lined by sandstone bluffs which contribute little to the lake's turbidity. Much of the area, however, is lined with mud banks which, in some areas, have eroded badly and account for much of the lake's inorganic turbidity. The soils are fairly old and well leached. Most of the catchment consists of forested and other relatively undisturbed land.

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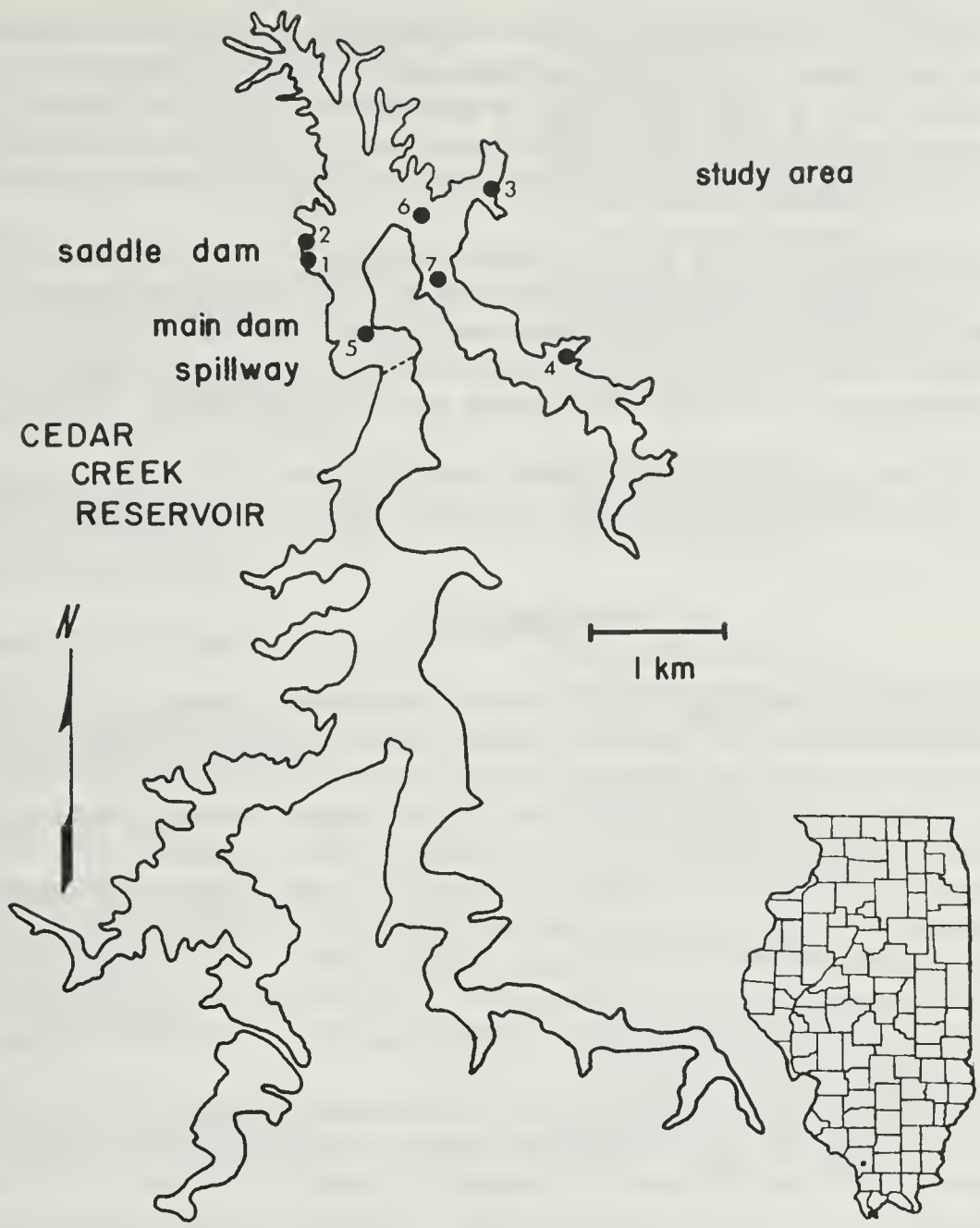

Figure 1. Cedar Creek Reservoir showing study area and sampling stations.

METHODS AND MATERIALS

Net samples, obtained using a very fine (120u) plankton net were used to augment sedimentation samples for floral identification. These samples were taken at irregular intervals from each of the stations shown in Figure 1. Samples were examined while fresh and again after preservation with Lugol's solution (1:100 dilution). For critical examination of diatoms, aliquots of several samples were cleaned in 25% aq H_2SO_4 for three hours at 90 C. A few crystals of $KMnO_4$ were added near the end of the digestion to oxidize any remaining organic material. References used for identification of the phytoplankton are listed in the appended bibliography.

Quantitative samples were taken monthly from March 1974 to March 1975 at each station in a 1 nota 1 butan 1 polyethylene bottle. These samples were taken at a depth of 25 cm and preserved with Lugol's solution shortly after collection. The samples were then concentrated to a volume of

10 ml using a sedimentation-decantation regime. Quantitative data were obtained by Lackey's micro transect method (Edmondson, 1969), and were expressed as cells per liter or in the case of species density, species per 5 transects which is equivalent to 0.39 ml of lake water. Palmer's generic index of organic pollution (Palmer, 1969) was used to determine water quality at station 6 and near shore stations. Nygaard's quotients (Nygaard, 1949) were used to determine the lake's tropic level.

Water temperatures were taken with a standard laboratory thermometer (at the collection depth). Hydrogen ion activities were determined with a PORTO-matic pH meter (IL model #175) and narrow range pH paper. Calcium, total hardness, nitrate, tannins and lignins, silica, sulphate, and ammonia analyses were performed using standard photometric techniques with a Hach DR/2 portable spectrophotometer. Chemical tests were run in duplicate on 3-16-74, 9-22-74 and 3-22-75.

Precipitation and other meteorological data were obtained from the University of Illinois, Southern Illinois University co-operative small fruits experiment station located 2 miles north of the research area.

RESULTS

A total of 94 species representing 6 divisions were identified. These are listed in Table 1 following, in general, the classification of Prescott (1962). Although most are euplanktonic forms, some tychoplankters from near shore stations have been included. Palmer's index ratings are shown in Table 2. Nygaard's myxophycean, chlorophycean, diatom, euglenine and compound quotients near the end of the study, were 9/10, 24/10, 11/14, 4/33 and 48/10 respectively. Total cell densities calculated for station 6 collections are shown in Figure 2. Figure 3 shows cell densities by division. Counts made from several station 7 collections, as a check on station 6 results, were similar in all cases. Near shore stations, however, were quite variable due to local factors and for this reason quantitative data for these sites are not presented. The number of species encountered in five transects, equivalent to 0.39 ml of lake water, was calculated for station 6 collections and these values are shown in Figure 4 and Table 3.

No significant differences were found among chemical data obtained from near shore and mid-lake samples except that pH values were slightly higher at the former. All pH values were between 7.3 to 7.8. Representative chemical data are shown in Table 4. Variation from the values given was less than 10% for all sites and sampling times. A water temperature vs. time plot obtained from station 6 data is shown in Figure 5.

Table 1. Algal taxa found in Cedar Creek Reservoir from March 16, 1974 to March 22, 1975

CYANOPHYTA
MYXOPHYCEAE
CHROOCOCCALES

Coelosphaerium sp.
Dactylococcopsis sp.
Gloeocapsa punctata Nägeli
Merismopedia tenuissima Lemmermann
Microcystis aeruginosa Kützing

HORMOGONALES

Anabaena oscillarioides Bory
Anabaena spp. (2)
Oscillatoria sp.

CHLOROPHYTA
CHLOROPHYCEAE
VOLVOCALES

Carteria cordiformis (Carter) Dill.
Chlamydomonas sp.
Pandorina morum (Müller) Bory

TETRASPORALES

Elakatothrix viridus (Snow) Printz.
Sphaerocystis schroeteri Chodat
Tetraspora sp.

ULOTRICHALES

Stigeoclonium tenue (Agardh)

Kützing
Ulothrix sp.

OEDOGONIALES

Oedogonium sp.

CHLOROCCALES

Ankistrodesmus falcatus (Corda) Ralfs
Ankistrodesmus falcatus (Corda) Ralfs var. *mirabilis* (W. & G.S. West) G.S. West
Botryococcus braunii Kützing
Coelastrum microporum Nägeli
Crucigenia rectangularis (Nägeli) Gay
Crucigenia tetrapedia (Kirchner) W. & G.S. West
Dictyosphaerium pulchellum Wood
Franceia droescheri (Lemmermann) G.M. Smith
Kirchneriella obesa (W. West) Schmidle
Lagerheimia subsalas Lemmermann
Micractinium pusillum Fresnius
Micractinium quadrisetum (Lemmermann) G.M. Smith
Oocystis borgei Snow
Pediastrum duplex Meyen
Scenedesmus arcuatus Lemmermann
Scenedesmus bicaudatus (Hansgirg) Chodat
Schroederia ancora G.M. Smith
Schroederia setigera (Schröder) Lemmermann
Selenastrum minutum Nägeli
Tetraedron constrictum G.M. Smith
Tetraedron gracile (Reinsch) Hansgirg
Tetraedron minimum (A. Braun) Hansgirig
Tetraedron regulare Kützing var. *torsum* (Turner) Brunnthaler
Treubaria triappendiculata Bernard

ZYGNEMATALES

Arthrodesmus octocrone Ehrenberg
Closterium gracile Brebisson
Closterium leibleinii Kützing
Cosmarium punctulatum Brebisson
Euastrum binale Ehrenberg
Gonatozygon kinahani (Arch.) Ragenhorst
Hyalotheca mucosa (Dilw.) Ehrenberg
Mougeotia sp.
Spirogyra spp. (3)
Staurastrum gracile Ralfs
Staurastrum leptocladum var. *sinuatum* Wolle
Staurastrum margaritaceum (Ehrenberg) Meneghini
Staurastrum polymorphum Brebisson
Zygnema sp.

EUGLENOPHYTA
EUGLENOPHYCEAE
EUGLENALES

Euglena sp.
Trachelomonas sp.
Trachelomonas stokesiana Palmer
Trachelomonas volvocina Ehrenberg

CHRYSOPHYTA
XANTHOPHYCEAE
HETEROCOCCALES

Ophiocytium sp.

CHRYSOPHYCEAE
CHRYSOMONADALES
Dinobryon divergens Imhof.
Mallomonas caudata Ivanhof.
Synura uvella Ehrenberg

BACILLARIOPHYCEAE
CENTRALES

Attheya zachariasi Brun.
Cyclotella bodanica Eulenstein
Cyclotella glomerata Bachmann
Cyclotella meneghiniana Kützing
Cyclotella stelligera Cl. U. Grun.
Melosira distans Ehrenberg
Melosira granulata (Ehrenberg) Ralfs
Melosira granulata (Ehrenberg) Ralfs var. *angustissima* O. Muller
Melosira varians C.A. Agardh
Rhizosolenia eriensis H.L. Smith
Rhizosolenia longiseta Zachary
Stephanodiscus subtilis Van Goor

PENNALES

Asterionella formosa Hassall
Cymbella prostrata Berkeley
Gomphonema acuminatum Ehrenberg

Gomphonema olivaceum (Lyngby) Kutzing
Gyrosigma acuminatum (Sullivant) Boyer
Hantzschia sp.
Navicula hungarica Grunow var. *capitata* (Ehrenberg) Cleve.
Navicula sp.
Pinnularia sp.
Rhopalodia gibba (Ehrenberg) O. Müller
Surirella linearis Wm. Smith
Synedra acus Kützing
Synedra acus Kützing var. *radians* (Kützing) Hustedt
Synedra ulna (Nitzsch) Ehrenberg var. *aequalis* (Kützing) Hustedt
Synedra sp.

PYRRHOPHYTA
DINOPHYCEAE
PERIDINIALES

Ceratium hirudinella (O.F. Müller) DuJardin
Ceratium hirudinella (O.F. Müller) DuJardin var. *furcoides* (Schröder) Huber-Pestalozzi
Peridinium pusillum (Penard) Lemmermann

CRYPTOPHYTA
CRYPTOPHYCEAE
CRYPTOMONADALES

Chroomonas nordstedtii Hansgirg
Cryptomonas ovata Hansgirg

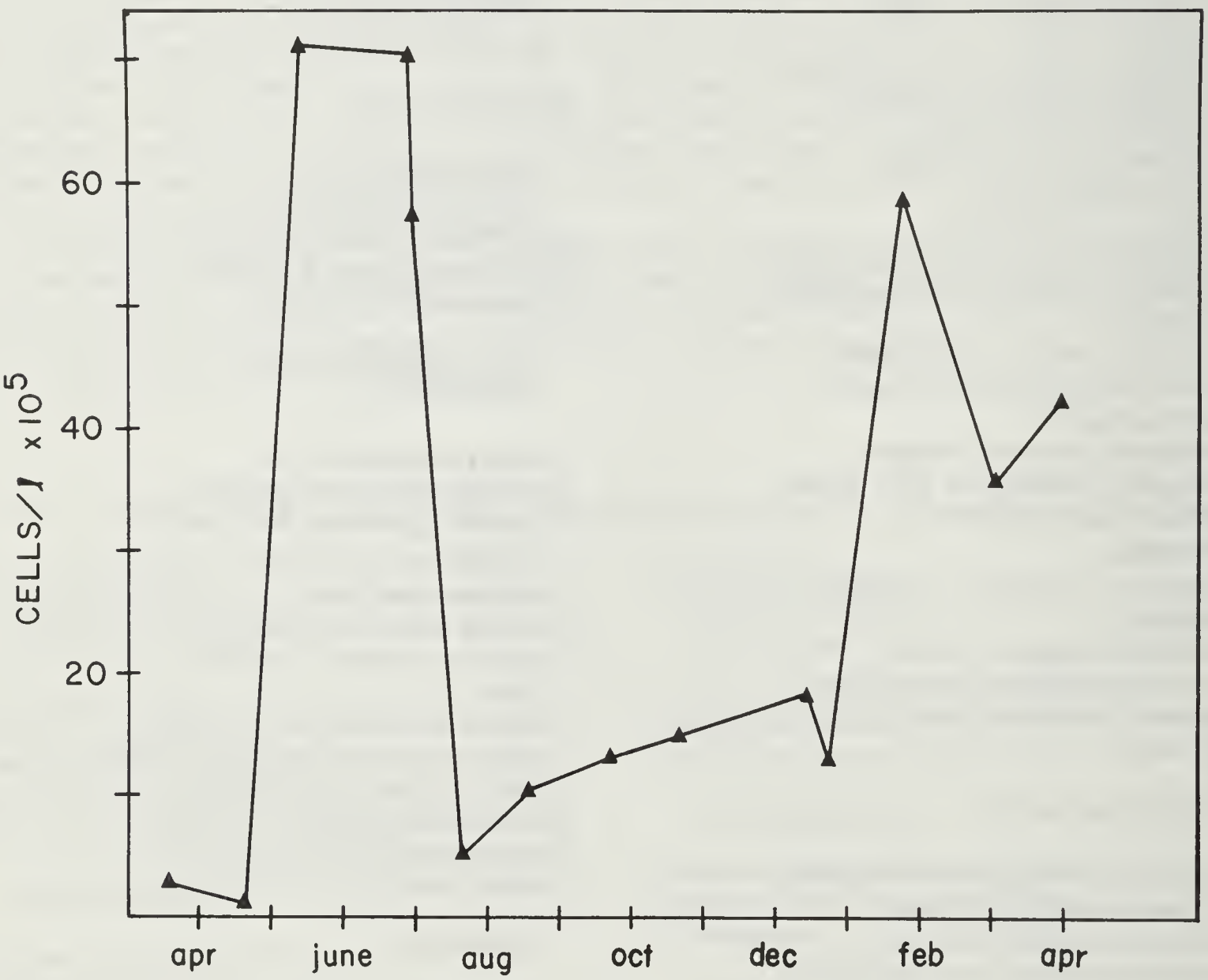

Figure 2. Total cell density observed at station 6 from March 16, 1974 to March 22, 1975

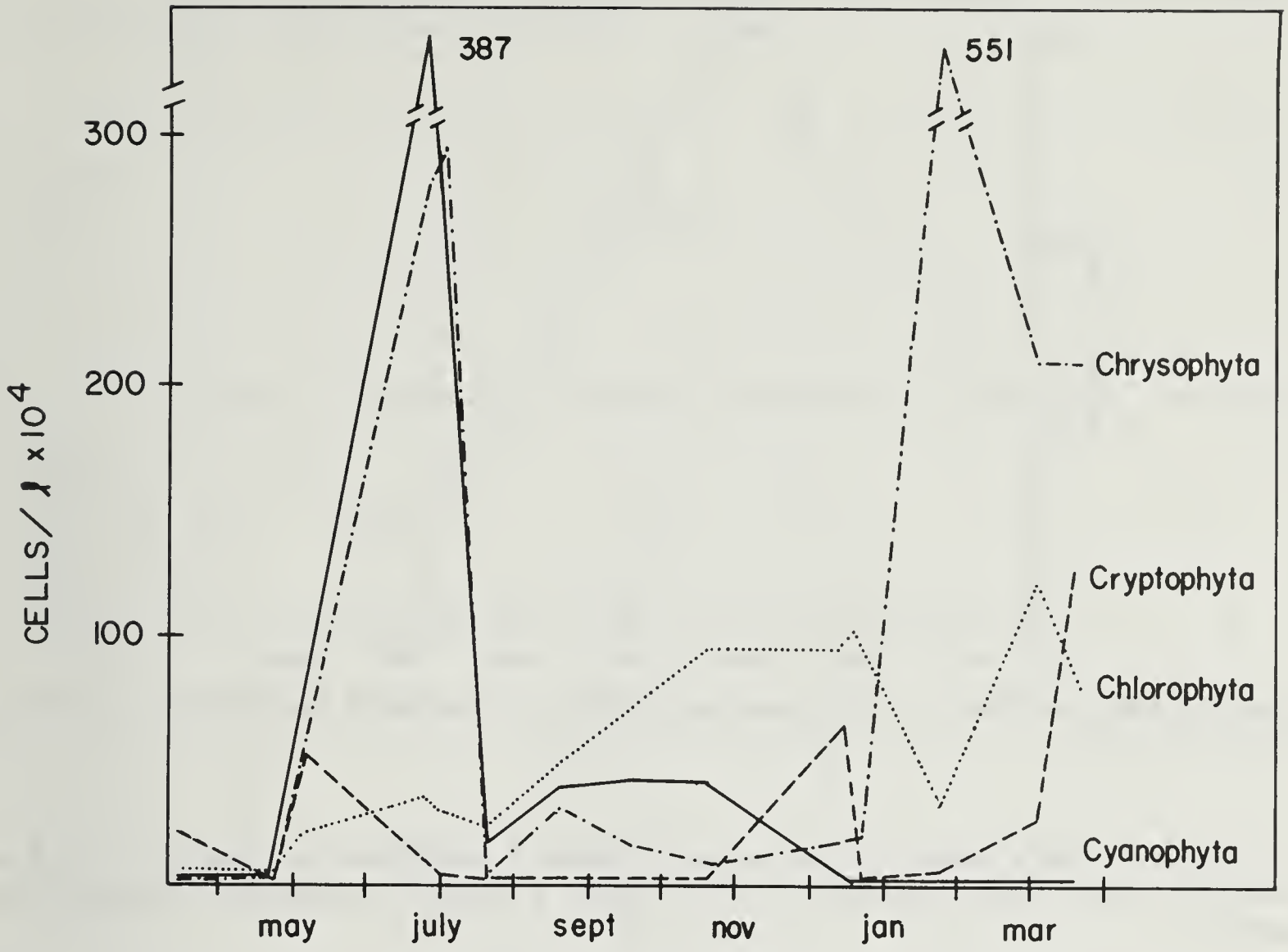

Figure 3. Cell densities by division observed at station 6 from March 16, 1974 to March 22, 1975

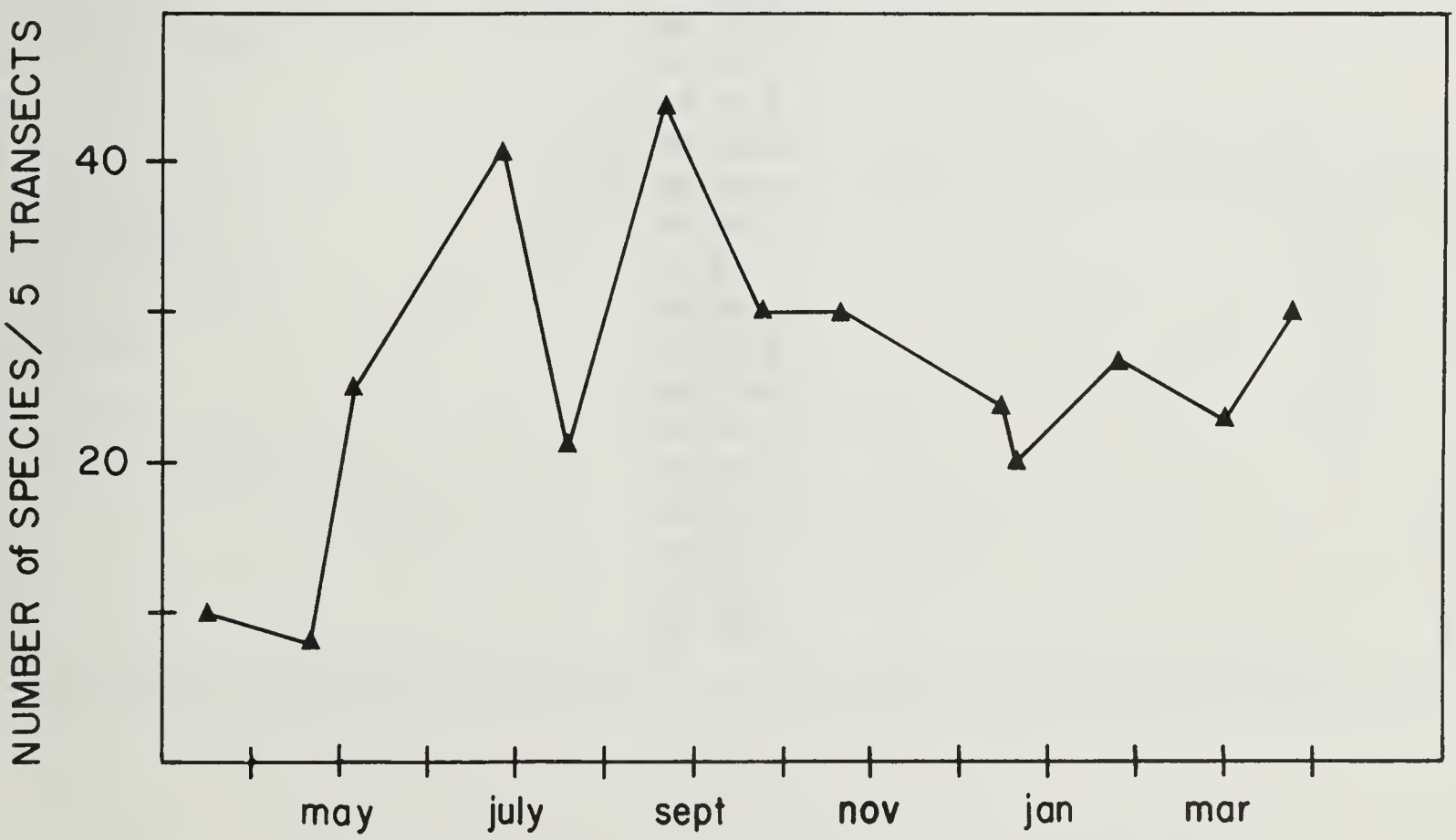

Figure 4. Total species density for station 6 from March 16, 1974 to March 22, 1975

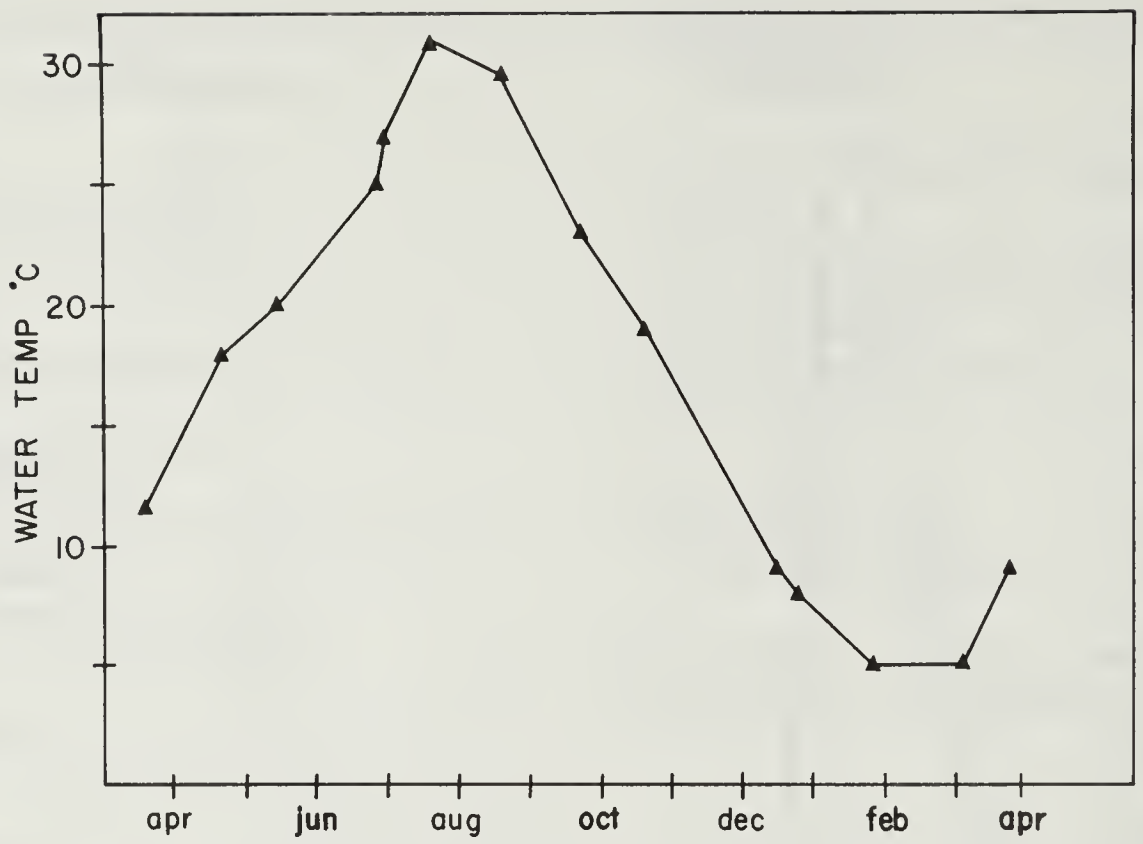

Figure 5. Water temperature, at sampling depth (25 cm), at station 6 from March 16, 1974 to March 22, 1975

Table 2. Palmer's pollution index values for station 6 collections from March 16, 1974 to March 22, 1975. (Values for March 16, 1974, sites 1, 3, and 5, are included for comparison with site 6.)

site	date	index
1	3-16-74	2
3	3-16-74	14
5	3-16-74	9
6	3-16-74	6
6	4-20-74	3
6	5-12-74	11
6	6-26-74	19
6	6-29-74	13
6	7-18-74	11
6	8-20-74	23
6	9-22-74	6
6	10-20-74	11
6	12-15-74	17
6	12-21-74	9
6	1-25-75	14
6	3-02-75	12
6	3-22-75	13

Table 3. Species density (number of species encountered in 5 transects) by division for station 6 from March 16, 1974 to March 22, 1975

Collection Date	Division					
	Pyrrophyta	Cryptophyta	Chlorophyta	Euglenophyta	Chrysophyta	Cyanophyta
3-16-74	0	2	4	1	3	1
4-20-74	0	2	5	1	3	1
5-12-74	0	2	9	2	10	2
6-26-74	0	2	15	2	17	3
6-29-74	1	0	10	1	17	3
7-18-74	1	2	9	1	6	3
8-20-74	0	1	21	3	14	3
9-22-74	0	1	13	1	10	1
10-20-74	0	1	14	2	7	4
12-15-74	0	2	11	2	7	1
12-21-74	0	1	9	1	8	1
1-25-75	1	2	11	1	11	1
3-02-75	0	2	11	1	9	0
3-22-75	0	2	15	1	11	0

Table 4. Representative concentration of select chemical entities in Cedar Creek Reservoir (site 6, March 16, 1974)

Chemical entity	Concentration (ppm)
Total hardness	50.0
Calcium hardness	35.0
Nitrate	0.8
Ammonia	0.3
Silica	2.8
Sulphate	13.0
Tannins and Lignins	0.4

DISCUSSION

A phytoplankton complement of 94 species is somewhat lower than those reported for many oligotrophic lakes. It compares favorably, in number, however, with the 79 species reported for Lake Mead by Staker, et al. (1974) who attribute their low value to eutrophic conditions.

The trend toward higher species density values with age has been observed in other newly formed bodies of water (Hodgkiss, 1974). Minckley and Tindall (1965) reported a ''sparse'' flora and fauna in Doe Valley Lake during impoundment. Both dilution effects and introduction of species are probably involved in the initial, low species densities and subsequent rise observed in Cedar Creek Reservoir (Fig. 4.). It is likely that certain organisms in the original stream population are suited for growth in a lacustrine environment, but not under environmental conditions that occurred between September, 1973 and February, 1974. These organisms would be diluted by an enormous factor as the pool level rose. It is also likely that species not found in the original stream population have been introduced to the new environment, by birds and other vectors, from similar habitats (Smith, 1924). Both the original and introduced populations would not be detected until environmental conditions favored their rapid reproduction.

The general increase in the total number of species with reservoir age is primarily the result of increases observed in the Chlorophyta and Chrysophyta (Table 3). The increase observed in the Chlorophyta was slightly greater than that observed in the Chrysophyta. The Pyrrophyta, Cryptophyta and Euglenophyta exhibited no overall increase in number of species. These unicellular motile algae are reported to be early successional forms (Eddy, 1925) and would most likely be adapted for early growth in newly formed lakes and ponds. Thus they would reach detectable levels before those organisms which thrive only in mature bodies of water. Cryptomonads were dominant in early samples from all seven stations. The Cyanophyta showed no general increase but this is probably related to the rather strict seasonality of this group (Smith, 1950). An increase in species density was observed until water temperatures cooled at which time the density values fell back to their spring level.

The number of species detected per division varied seasonally in the Cyanophyta, Chlorophyta, Euglenophyta, and Chrysophyta (Table 3). The number of species of cyanophytes increased during the summer and fall when water temperatures were above 18 C. Optimum growth of these organisms has been observed at these temperatures in other temperate lakes (Fogg, 1965). The number of species of Chlorophyta increased during the summer with a maximum immediately following the highest water temperature. The chrysophytes also exhibited a summer peak but it was skewed toward the spring and lower in amplitude. The Euglenophyta showed higher values at warmer temperatures and the Cryptophyta had larger values during the spring. The highest total species density closely followed the temperature maximum. Meyer and McCormick (1971) also encountered greater numbers of species during the spring and summer in an eight acre lake. Kofoid (1908) had previously observed this type of summer increase in the algae of the Illinois River.

The overall rise in total cell densities during the filling period (Fig. 2) may be characteristic of new reservoirs. Funk and Gaufin (1971) encountered no high densities for an entire year following the impoundment of a 465 ha Wyoming lake. Even the early peaks, recorded during the second summer after impoundment, exhibited relatively low densities (1×10^6 cells/l). Larger densities were encountered (upon filling) during the third summer. Hammer and Hergenrader (1971) observed similar results in Branched Oak Reservoir. In a study of Evergreen lake (near Bloomington, Illinois) Sievert et al. (1975) concluded that normal populations were established soon after filling.

Spring algal blooms are common features of temperate lakes. Such an increase was observed in Cedar Creek Reservoir, but, it occurred somewhat later than might be expected (Fig. 2). The first peak in cell density, occurred from May through June 1974, and was due to large populations of *Merismopedia tenuissima, Melosira distans* and one species of *Anabaena* (Fig. 3). The *Anabaena* species was dominant early in the peak with smaller numbers of *Chroomonas nordstedtii* and *Melosira distans*. *Merismopedia tenuissima* then became the most abundant form, with *Melosira distans* in only slightly lower densities, and significant densities of the *Anabaena* species and *Microcystis aeruginosa*. Near the end of the peak, *Melosira distans* was dominant with the *Anabaena* species close behind and a small amount of *Asterionella formosa*. This peak is unusual in that the blue-greens usually peak after other organisms such as diatoms or greens. This may be a result of higher water temperatures associated with the delayed nature of this ''bloom''. Hammar

and Hergenrader (1971) noted a similar blue-green "bloom" in Branched Oak Reservoir during June of the second year after impoundment. Funk and Gaufin (1971) noted an early summer peak, with *Pandorina morum* and *Aphanizomenon flos-aquae* as co-dominants, soon after the impoundment of Lake Viva Naughton.

The second peak (Fig. 2) was unusual in that it occurred when the water temperature was at its minimum, about 5 C. A fall peak is a common feature of temperate lakes but winter peaks are rare. This peak, due to *Stephanodiscus subtilis* and *Melosira distans* in a ratio of approximately 3:1 (Fig. 3), could be a result of mixing. However, since ice formed only at the lake edges and the water temperature remained relatively high, conditions were suitable for a rapid increase in cell density of the chrysophytes which are known to prefer cool temperatures (Smith, 1950). Diatoms have even been detected in high concentrations under ice (Funk and Gaufin, 1971: Fogg, 1965).

The sharp drop in cell densities which terminated each peak does not appear to be related to precipitation or other meteorological factors. The rapid drop in chrysophyte populations may have resulted from depletion of dissolved silica since this component was present in low concentrations in all samples tested (Table 4).

Diatoms, except during "blooms", constituted less than 30% of the total cell density. Damann (1945) stated that the phytoplankton of streams and small rivers is composed of at least 90% diatoms. If this was the case with Cedar Creek, impoundment has caused a marked decrease in their relative abundance. Settling is probably a key factor responsible for this difference.

The cell density of chlorophytes increased in general throughout the study (Fig. 3). The chlorophytes were dominant between the two total cell density peaks. Chlorophytes have commonly been observed as dominants after the spring peak in temperate lakes and ponds (Taylor, 1972: Moss, 1972). *Ankistrodesmus falcatus* var. *mirabilis* was the most abundant green alga with cell densities near 5×10^5 cells/l. The warm water increase observed in blue-green cell densities is also typical.

Palmer's index values indicated that nearly all samples were free from high organic pollution (Table 2). The August 1974 sample, immediately following the first "bloom" at station 6, was the only sample that positively indicated high organic pollution. Two other samples showed probable signs of high organic pollution. The lake was certainly oligotrophic before the first "bloom" occurred, yet, Nygaard's indices indicated that by March 1975 Cedar Creek Reservoir was moderately eutrophic. These results must be accepted cautiously, however, since Brook (1965) has shown that Nygaard's indices are not always valid indicators of the trophic level of a lake. The relative abundances of chlorophytes ($\simeq$ 50%) and specifically desmids ($\simeq$ 10%) do not indicate eutrophic conditions (Staker et al., 1974). These vlaues may be a reflection of relatively low calcium concentrations (Table 4) (Fogg, 1965). There does, however, seem to be a trend toward eutrophic conditions when early and late samples are compared. Hammar and Hergenrader (1971) noted that heavy eutrophication occurred in several small reservoirs only a few years after impoundment. In Cedar Creek Reservoir, however, the nutrient levels are lower and water residence times are shorter. It seems logical to conclude then from our observations and comparisons with similar studies, that Cedar Creek Reservoir will be moderately eutrophic when mature.

In summary, this study has resulted in a fairly complete floral listing of those organisms appearing in the phytoplankton over one complete seasonal cycle. Comparison with similar listings obtained in later years should reveal valuable information about long range trends in phytoplankton composition as a function of reservoir maturity. The interpretation of variations in phytoplankton composition observed during and shortly after filling must remain tentative because of the paucity of work on newly formed reservoirs with which to compare our observations, and the wide latitude of yearly variations observed in established bodies of water. Additional studies on the phytoplankton of forming and newly formed reservoirs similar to Cedar Creek Reservoir should allow workers in this area to distinguish between those trends which can be attributed to the development of the flora and those which can be attributed to normal variations observed in established lakes.

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A SURVEY OF THE HERPETOFAUNA OF THE UPPER DES PLAINES RIVER VALLEY, LAKE COUNTY, ILLINOIS

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ABSTRACT

A survey of the herpetofauna of the Des Plaines River Valley in Lake County, Illinois was conducted on lands owned by the Lake County Forest Preserve District during the years 1974-1977. Identification of species was by recognition of breeding calls and observation of live trapped specimens. A list of 29 species and two subspecies historically inhabiting the study area was compiled and is presented with a list of species found during the survey. Twenty-five species, two subspecies, and intergrades between those subspecies were currently found to inhabit the river valley. Two species, Pseudemys scripta elegans *and* Terrapene c. carolina, *were believed to be "pet releases".*

INTRODUCTION

This paper is a herpetofaunal survey of the upper Des Plaines River Valley in Lake County, Illinois. Previously published herpetofaunal surveys that included the Des Plaines River in Lake County, were primarily annotated species lists (Cope 1900, Necker 1939, Schmidt and Necker 1935). Smith (1961) and Pope (1964) provided life histories and general distributional information for the herpetofauna in the region covered by this survey, based on both previous records and extensive collecting.

The immediate purpose of this survey was to determine the current status of species occurring in the various habitats along the river valley, and to note areas of population concentration and general abundance of individual species. The survey was restricted to lands owned by the Lake County Forest Preserve District along the approximate 35 mile length of the river valley within the county. The data presented were primarily collected from April through October 1975 in a concentrated effort for the Forest Preserve District. Personal observations and collections from the years 1974, 1976, and 1977 have also been included. Herpetofaunal nomenclature follows Smith (1961).

The eastern limit of the river valley is formed by the Park Ridge and Deerfield Moraines (Willman 1971), which in the southern part of the county has a vegetation cover dominated by oak-hickory *(Quercus alba/Carya ovata)* association. Sugar maple-basswood *(Acer saccharum/Tilia americana)* association occupies sections of the eastern floodplain that have remained undisturbed by agricultural and urban pressures. A narrow strip of silver maple-black willow-green ash *(Acer saccharinum/Salix nigra/Fraxinus pennsylvanica)* association forms the riparian habitat along both sides of the river. The west side, formerly prairie (Moran 1978), was intensively farmed until the study area was purchased by the Forest Preserve District. Much of this acreage is now in various stages of old field and secondary succession. The shallow river valley rises on the western edge to the Tinley Groundmoraine and sections of the Park Ridge Moraine. In the northern third of the county the forests fade and are replaced by expanses of fields with scattered bur oak *(Quercus Macrocarpa)* on the moraines, and wetlands of degraded prairie and reed canary grass on the floodplains. Urban development within the river valley, and particularly the floodplain, is not extensive and has to this date been primarily restricted to a few communities. Sand and gravel open-pit extraction has been practiced throughout the river valley, especially in the northern half of the county (Larsen 1973).

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METHODS

Salamanders were found and studied throughout the survey by overturning logs and decaying vegetative material. Salamanders were also live trapped with the aid of a drift fence around a breeding pond (Stebbins 1954).

Frogs and toads were observed throughout the survey and hand or net capture was attempted for closer investigation. A survey of breeding sites was conducted along the entire length of the river valley on several evenings in late May. Ponds and wet areas where the amphibians were expected to congregate were identified and mapped. Identification of herpetofauna was made by spring breeding call and was noted as either a few individuals or a chorus. Evening walks through forested areas were also conducted with identification again by breeding call.

Turtle data were collected through observation, hand capture, and live trapping. Live trapping was conducted with traps as described by Conant (1975) except constructed from Hardware cloth. Trapping was conducted from 20 May through 15 October 1975 at nine locations. These sites were chosen to represent a number of different habitat types along the river, as well as to cover the entire length of the river within the county. All turtles captured were marked by a distinctive notch in the edge of a lower right marginal to aid in identification of recaptured individuals.

Snakes were observed and hand captured if possible. Poisonous snakes were collected by use of Pillstrom Tongs.

During the 1975 herpetofauna survey, the Forest Preserve District was also conducting an aquatic survey of the river valley. Extensive seining to determine fish populations at times netted turtles and frogs. Data form these specimens were added to the herpetofauna survey. No members of Orders Caudata or Squmata were captured in this manner. All specimens captured during the surveys were released at point of capture after positive identification and recording of physical data.

RESULTS AND DISCUSSION

Salamanders

Salamanders were the first taxa to appear in the spring. At this early appearance the salamanders were moving toward breeding sites, and snow was often on the ground. Because of these early movements, the first efforts of the survey were directed toward live trapping at a breeding site.

The Blue-spotted salamander *(Ambystoma laterale)* was the only species of salamander collected during the 1975 live-trapping survey (Table 1). The drift fence surrounding a temporary pond was located in a second growth mixed white and red oak forest with a sugar maple understory (SE¼, SW¼, Sec. 26, T43N, R11E). The collection pits aligned with the drift fences were checked twice daily for specimens. Male Blue-spotted salamanders were the first to move toward the breeding pond and were first noticed on 15 April; the peak of the movement occurred on 20 April and movement of males ended on 25 April. Female movement started on 20 April, and peaked on 25 April. All movement in and out of the breeding pond ceased on 15 May. The drift fence was removed on 27 May. A total of 162 specimens of this species, 101 males and 61 females; were recorded entering the pond.

Blue-spotted salamanders were confined to the east side of the river in the southern third of the county. The species was common in mesic forest areas away from the immediate floodplain. The population appears to depend upon a few ponds that are large enough to contain water until the salamander's larvae are able to sustain themselves in the terrestrial environment. Most of the temporary ponds exist on property owned by the Forest Preserve District in Vernon (Sections 26,33) and Libertyville Townships (Section 34).

Spotted salamanders *(Ambystoma maculatum)* were only observed in mature portions of the oak/hickory association on the Deerfield Moraine in southern Lake County. Only two specimens were observed within the study area, both specimens were found under moist leaf litter in late September. Residents living near the study area on the moraine have accurately described specimens which they have found in basement window-wells, also during the autumn. This species is evidently common, but difficult to discover during most of the year.

The Tiger salamander was found in both the oak/hickory and sugar maple/basswood associa-

tions of the river valley, usually under logs or inside old stumps. This species is uncommon in the valley and, progressing northward, becomes increasingly difficult to find. Specimens were collected within the study area during the spring, late summer, and fall, particularly after heavy rains.

Neither the Central newt *(Notophthalmus viridescens louisianensis),* or the Four-toed salamander *(Hemidactylium scutatum)* were found during the survey. Pope (1964) refers to a single specimen of the Central newt captured in 1942 near the Des Plaines River in the extreme southern part of Lake County. The four-toed salamander is shown by Smith (1961) also to occupy the same region of the river valley. Both species are either quite rare, or no longer exist in these areas.

Frogs and Toads

The American toad *(Bufo a. americanus)* was the only member of the Order Salientia expected in the study area, and it inhabited ponds and wet areas along the entire length of the Des Plaines River. Thirty specimens were captured in drift fences set for salamanders, the earliest capture in this manner occurred on 18 April 1975. Scattered singing was heard that year throughout late April, peaked in mid-May and extended into early June.

Western chorus frogs *(Pseudacris t. triseriata)* were an abundant inhabitant of wetlands throughout the study area. Other species of frogs identified by both breeding call and observed specimens were: Blanchard's cricket frog *(Acris crepetans blanchardi),* Northern spring peeper *(Hyla c. crucifer),* and Eastern gray treefrog *(Hyla v. versicolor).* All were uncommon with scattered individuals heard singing during the spring near wet areas formed by a secondary perched water table in the oak/hickory forest upon the Park Ridge Moraine (Vernon Township, Sections 26, 33).

The Green frog *(Rana clamitans melanota)* was found along the entire river edge and was the most abundant herpetofaunal species observed in the river valley. Bullfrogs *(Rana catesbeiana)* were also observed along the entire river edge, but only as very scattered individuals.

A less common species, the Pickerel frog *(Rana palustris)* was only observed and captured once during this study. The specimen was captured in a low area near the river, a little south of the Wisconsin state line (Newport Township, Section 10).

Only a single specimen of the Eastern wood frog *(Rana s. sylvatica)* was heard singing in mature oak/hickory forest on the Park Ridge Moraine with the Ryerson Conservation Area (Vernon Township, Section 26). This specimen was heard during the evening of 12 April near a small temporary pond.

Turtles

A total of 128 turtles was captured during the live trapping portion of the turtle survey. Previous papers have discussed the various food habits of the turtles and it was known that the Western painted turtle *(Chrysemys picta belli)* is primarily herbivorous and insectivorous in its food habits. Fritsch (1940) also mentioned that this species was probably not a habitual scavenger. The results of this trapping technique, which used chunks of Carp as bait, show that all the species recorded, except the Eastern box turtle *(Terrapene c. carolina),* are scavengers to some degree.

Common snapping turtles *(Chelydra s. serpentina)* and Eastern spiny softshells *(Trionyx s. spinifer)* were trapped or observed in all areas of the river. The Common snapping turtle appears to be the most abundant species of the order Testudines, and also the largest. One specimen of this species had a carapace length of 353 mm. The Eastern and Western painted turtles *(Chrysemys picta marginata, C. picta belli)* also occur the entire length of the river. The intergrade, *Chrysemys picta marginata X belli,* was captured in all traps and the abundance of the intergrade demonstrates extensive interbreeding between the two subspecies that occur in the study area.

Three species of turtles were found to have very limited ranges within the river valley. Blanding's turtles *(Emydoidea blandingi)* were found only at the northern end of the river valley. Two specimens were observed, a male captured in a shallow portion of the river in a degraded prairie (Newport Township, Section 27). The Red-eared turtle *(Pseudemys scripta elegans)* was represented in the far-southern part of the river (Vernon Township, Section 26) by a single female specimen. This specimen was most likely a pet release; the species had not been previously known from the Des Plaines River in Illinois. Necker (1939) recorded a single specimen at Orland Park in Cook County. Two male specimens of the Eastern box turtle *(Terrapene c. carolina),* also con-

sidered to be pet releases, have been observed in the sugar maple/basswood forest within the Ryerson Conservation Area. The closest indigenous population of this species to the study area is in Porter County of Northwest Indiana (Pentecost and Vogt 1976).

Lizards and Snakes

Nine of the eleven species previously known as occurring within the river valley (Cope 1900, Necker 1939, Schmidt and Necker 1935) were found still to be present. Based on this survey only the Chicago garter snake *(Thamnophis sirtalis semifasciata)* appears to be common the length of the valley. Two specimens of Graham's water snake *(Natrix grahami),* observed on the river bank at either end of the county (Newport Township, Section 15; Vernon Township, Section 26), were the only representatives of the water snakes. The Western fox snake *(Elaphe v. vulpina)* was found with scattered populations in the northern half of the study area in both oak forest and grassland habitats. An Eastern milk snake *(Lampropeltis t. triangulum) and a Eastern plains garter snake (Thamnophis radix)* were each represented by a single specimen on the west side of the river (Libertyville, Township, Section 15); both were found in old field habitat and are evidently uncommon. The Northern redbellied snake *(Storeria o. occipitomaculata)* occupied forested areas in the southern half of the valley. De Kay's snake *(Storeria dekayi wrightorum)* was also common in the southern half of the valley, but it only occurred in or near the oak/hickory association along the Park Ridge Moraine. Several specimens of the Western smooth green snake *(Opheodrys vernalis blanchardi)* were collected in an old field habitat on the west side of the river (Vernon Township, Section 33). This was the only location where this species was found and is evidently the site of a small colony. The Eastern massasauga *(Sistrurus c. catenatus)* occupied grassland and old field habitats as well as oak forest edges in the southern end of the valley (Vernon Township, Sections 26, 33). The rattlesnakes were uncommon within this limited area, even though the species tends to congregate and may appear to be common near den sites (Bushey 1978, Wright 1941).

No lizards were observed or collected, although areas of suitable habitat were specifically searched for the Five-lined skink *(Eumeces fasciatus)* during the salamander and snake surveys. Cope (1900) recorded finding a specimen in Lake County, but not within the Des Plaines River Valley.

Due to the lack of previous information it is difficult to determine if any one species population has increased or decreased due to changes in the quality or quantity of available habitat. This survey only verified the occurrence of species living within the study area as of 1977 and the possibility exists of additional species either traveling, or being introduced into the area and establishing viable populations. The occurrence of pet releases has been demonstrated, and additional herpetofaunal species exist relatively near the river valley.

None of the species found during the herpetofaunal survey were listed by the Illinois Endangered Species Protection Board (1978), as either endangered or threatened within the state.

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Table 1. Herpetofauna of the Des Plaines River Valley in Lake County, Illinois and their observed habitats.

	Indigenous Species[1]	1974-1977 Survey	Observed Habitat[2]
Class Amphibia			
Order Caudata (Salamanders)			
Ambystoma laterale Hallowell	X	X	M,O
Ambystoma maculatum (Shaw)	X	X	O
Ambystoma tigrinum tigrinum (Green)	X	X	M,O
Notophthalmus viridescens louisianensis Wolterstroff	X		
Hemidactylium scutatum (Schlegel)	X		
Order Salientia (Frogs and Toads)			
Bufo americanus americanus Holbrook	X	X	M,O,RM,RG
Acris crepitans blanchardi Harper	X	X	O
Pseudacris triseriata triseriata (Wied)	X	X	O
Hyla crucifer crucifer Wied	X	X	M,O,OF,RG
Hyla versicolor versicolor LeConte	X	X	O
Rana catesbeiana Shaw	X	X	RM,RG,R
Rana clamitans melanota (Rafinesque)	X	X	RM,RG,R
Rana palustris LeConte	X	X	RG
Rana pipiens pipiens Schreber	X	X	RM,OF,RG
Rana sylvatica sylvatica LeConte	X	X	O

Class Reptilia

Order Testudines (Turtles)

Chelydra serpentina serpentina (Linnaeus)	X	X	R
Emydoidea blandingi (Holbrook)	X	X	RG,R
Terrapene carolina carolina (Linnaeus)		X	M
Chrysemys picta marginata Agassiz	X	X	R
Chrysemys picta bella (Gray)	X	X	M,R
Chrysemys picta marginata X bella		X	R
Pseudemys scripta elegans (Wied)		X	R
Trionyx spinifer spinifer LeSueur	X	X	R

Order Squamata (Lizards and Snakes)

Opheodrys vernalis blanchardi Grobman	X	X	OF
Elaphe vulpina vulpina (Baird & Girard)	X	X	OF,G
Lampropeltis triangulum triangulum (Lacépède)	X	X	OF
Thamnophis radix radix (Baird & Girard)	X	X	OF
Thamnophis sirtalis semifasciata (Cope)	X	X	O,OF,G
Storeria dekayi wrightorum Trapido	X	X	O,OF
Storeria occipitomaculata occipitomaculata (Storer)	X	X	M,O,OF
Natrix grahami (Baird & Girard)	X	X	RM,RG,R
Natrix septemvittata (Say)	X		
Natrix sipedon sipedon (Linnaeus)	X		
Sistrurus catenatus catenatus (Rafinesque)	X	X	O,OF,G

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[1] Based on annotated list of species (Cope, 1900); (Necker, 1939); (Schmidt and Necker, 1935); and species range maps (Smith, 1961).

[2] Habitat codes: Forest; sugar maple/basswood (M), oak/hickory (O), riparian - silver maple/black willow/green ash (RM), Old Field; (OF), Grassland; mesic grassland (G), riparian - wet grassland (RG), River; (R).

A Revision of *Heteromurus* s. str. (Insecta: Collembola: Entomobryidae)[1]

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ABSTRACT

The revision includes descriptions of five of the seven species, a key to all the species and a phyletic analysis of the taxon. Complete synonymy and geographic distribution are detailed for all the taxa H. caucasicus and *H. mexicanus* are new synonyms of *H. major H. hexophthalmus* and *H. tetrophthalmus* are new synonyms of *H. sexoculatus* and *H. nitidus* respectively.

INTRODUCTION

The genus *Heteromurus* Wankel 1860 includes four subgenera: the nominal subgenus, *Verhoeffiella* Absolon 1900b, *Alloscopus* Borner 1903, and *Heteromurtrella* Mari Mutt 1979a. *Alloscopus* was reviewed by Mari Mutt (1978a). The status of *Verhoeffiella* and its five species is uncertain, very few specimens are in collections and these are not available for study. All species of *Verhoeffiella* are troglobitic and only one has been collected (once) since its description. A meaningful revision of this taxon must await the discovery of specimens for the study of important characters not mentioned in the original descriptions.

This paper presents a revision of the nominal subgenus, *Heteromurus* s. str., in which I recognize two species groups and seven species. The edaphic *H. gigans* and the cavernicolous *H. noseki* were described recently (Mari Mutt and Stomp 1980) and will not be dealt with here except for their inclusion in the key to the species of the subgenus.

The *nitidus* group includes *H. nitidus, noseki* and *peyerimhoffi;* the *major* group houses *H. major, gigans* and *variabilis.* Species of the nitidus group share the following characteristics: a double row of smooth setae along inner margin of tibiotarsi, a double row of smooth erect setae along dorsum of manubrium and a pair of similar setae upon the proximal dorsal portíon of the dentes; only smooth setae on the labial triangle and rest of venter of head; 2&2, 1&1, or eyes absent, and all the species occur in caves two being restricted to this habitat. Species of the *major* group share the following characteristics: only ciliated setae upon tibiotarsi and manubrium; labial triangle and rest of venter of head with smooth setae and ciliated setae; 8&8 eyes, and all the species are edaphic.

The seventh species, *H. sexoculatus,* is intermediate between these otherwise clear-cut groups. It presents: only ciliated setae upon the tibiotarsi; a double row of smooth erect setae along dorsum of manubrium and a pair of similar setae upon the dentes; labial triangle with smooth or ciliated setae; 3&3 eyes, and it occurs both inside and outside caves (troglophilic). Following the results of a preliminary phytletic analysis (see section on phylogeny), I have placed *sexoculatus* in the *major* group.

A series of abbreviations are used throughout this paper to indicate the depository of specimens. These are: BMNH-British Museum (Natural History), Department of Entomology, Cromwell Rd., London SW7 5BD, England; HJG-H.J. Gough collection, Jealott's Hill Research Station, Brecknell Berkshire RG 12 6 EY, England; INHS-Illinois Natural History Survey, Division of Faunistics Surveys, Natural Resources Bldg., Urbana, Illinois 61801; JAB-J.A. Barra collection, Institut de Zoologie, 12 rue de l'Universite, 67000 Strasbourg, France; JAMM-J.A. Mari Mutt collection, Department of Biology, University of Puerto Rico, Mayaguez, Puerto Rico 00708; KAC-K.A. Christiansen collection, Department of Biology, Grinnell College, Ginnell, Iowa 50112; LSU-

[1]This article is based, in part, on a thesis deposited by the author in the Graduate College of the University of Illinois at Urbana-Champaign in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Entomology, 1978.

Leningrad State University, Laboratory of Entomology, Biological Research Institute, Leningrad, USSR; MNHN Museum National d'Histoire Naturelle, Ecologie Générale, 4 Avenue du Petit Chateau, 91800 Brunoy, France; NS-N. Stomp collection, Athénee Grand-Ducal de Luxembourg, 24 boulevard Pierre Dupong, Luxembourg; NZNM-New Zealand National Museum, Private Bag, Wellingotn, New Zealand; PAS-Polish Academy of Sciences, Institut of Systematic and Experimental Zoology, Stawkowska 17, Krakow, Poland; SAS-Slovak Academy of Sciences, Institute of Virology, Bratislava 9, Czechoslovakia; USNM-United States National Museum of Natural History, Department of Entomology, Smithsonian Institution, Washington, D.C. 20560. WNE-W.N. Ellis collection, Zoology Museum, University of Amsterdam, Netherlands.

PHYLOGENY

The most important procedure of cladistic analysis is the determination of the ancestral (plesiomorphic) and derived (apomorphic) states of each character used. To solve this problem the worker must frequently go outside his group to more primitve taxa in order to study there the expressions of the characters concerned.

The work of Szeptycki (1972, 1979) and my own suggests that the Orschesellinae are the most primitive entomobryids and that their closest relatives outside of this family lie in the subfamily Isotominae of the Isotomidae. Comprehensive comparative studies in this group are unfortunately lacking. The worker finds that he has more than enough characters to separate the species but not enough for which the ancestral and derived states can be determined with much certainity.

Based on the examination of some isotomids and of scattered literature on this group, I have tentatively designated ancestral and derived states for nine characters in the subgenus.

Ancestral Alternative	*Derived Alternative*
1. 8&8 eyes	1a. 3&3 1b. 2&2, 1&1 or absent
2. edaphic	2. in caves
3. unguis up to 2.5 x width of tibiotarsus at level of tenent hair	3. 3.3 x width of tibiotarsus at same level
4. mucronal teeth normal	4. teeth modified (Fig. 17)
5. microchaetae abundant, scales not so abundant	5. microchaetae scarce, scales very abundant
6. setae of labial triangle smooth	6a. smooth and ciliated 6b. all setae ciliated 6c. smooth setae, ciliated setae, and scales
7. setae of PLQ smooth	7. ciliated
8. tibiotarsi with smooth setae	8. all setae ciliated
9. dorsum of manubrium with smooth setae	9. all setae ciliated

The decision to regard smooth setae as ancestral to ciliated setae is most important. Figure 1 presents the proposed phyletic relationships of the seven species of *Heteromurus* s. str. Note the trichotomy in the *major* group; the ancestral and derived states of more characters must be determined to solve it.

TAXONOMY

Genus *Heteromurus* Wankel

Heteromurus Wankel 1860: 203. Placed on the Official List of Generic Names in Zoology with the name number 2034 by the International Commission on Zoological Nomenclature, opinion 1064 (ICZN 1976).
Ptenura Templeton 1844: 306. Placed on the Official List of Rejected and Invalid Names in Zoology with the name number 2074 by the International Commission on Zoological Nomenclature, opinion 1064 (ICZN 1976).
Templetonia Lubbock 1862: 595. Absolon 1900a: 192.
Typhlopodura Absolon 1900b: 428. Kseneman 1937: 69-70. Gisin 1944: 96. Gisin 1960: 237. Salmon 1964: 133, 487.
Euheteromurus Borner 1901: 64. Salmon 1964: 131, 478.
Heteromurodes Absolon 1901: 12. Salmon 1951: 25. Salmon 1964: 131, 478.
Propemesira Salmon 1942: 59. Salmon 1945: 71. Salmon 1964: 131, 478.

Type Species: Heteromurus margaritarius Wankel 1860: 203, by monotypy. Name of species placed on the Official List of Specific Names on Zoology with the name number 2584 by the International Commission on Zoological Nomenclature, opinion 1064 (ICZN 1976).

Subgenus *Heteromurus* s. str.

Adults 2-5 mm. Pigment absent, restricted to eye patches, or more or less evenly distributed throughout specimen. Most species with variable color pattern. Pigment, when present in preserved specimens, dark-blue (in *nitidus* sometimes orange). Legs scaled (except in *peyerimhoffi).* Antennae about ½ length of head and body combined. Apex of Ant. 5 with pin seta, without apically hooked setae. Eyes 8&8, 3&3, 2&2, 1&1, or absent, number constant intraspecifically (except in *nitidus* where last 3 combinations occur). Head macrochaetotaxy identical for all species (Fig. 28); Ps and S_0 absent, 2 P setae[2]. Labral papillae of type II (4 thick conelike papillae without apical process-Fig. 11), of type III (outer pair rounded, slightly domelike; inner pair strongly conelike-Fig. 18-19), or absent. Labial chaetotaxy variable intra- and interspecifically; posterior row with all setae smooth, all ciliated, smooth setae and ciliated setae, or some setae substituted by scales *(gigans).* Setae of maxillary palp similar in all species (Fig. 27). Differentiated seta of outer labial papilla short and slender (Fig. 4) or long and thick at base (Fig. 16, 25, 30). Postlabial quadrangle (PLQ- 4 setae, 2 on each side of median cleft, behind labial triangle - Fig. 29), of smooth or ciliated setae depending on species; other setae of venter of head smooth or ciliated, both types present in some species. Tibiotarsi, in *nitidus* group, with a double row of smooth setae along inner margin, all leg segments with ciliated setae. Ungues bi-, tri-, or quadri-dentate; all types present in *nitidus,* more than one type may be present in other species. Unguiculus almost always with an outer tooth that is never winglike. Inner margin of unguiculus toothless. Tenent hair apically lanceolate or clavate, both types in some species. Body macrochaetotaxy identical for all species (Fig. 5) except for second thoracic segment (Th. 2) of *peyerimhoffi* (Fig. 22). First abdominal segment (Abd. 1) of adults without macrochaetae. Dorsum of furcula interspecifically with or without smooth erect setae. Dental spines absent. Mucro with basal spine (except in some *nitidus).*

Diagnosis. Mari Mutt (1979a) presented a key to the subgenera of *Heteromurus* which details the differences between these taxa. Briefly, the nominal subgenus may be separated from *Verhoeffiella* by the presence of annulations on Ant. 5 (on both Ant. 4 and Ant. 5 in *Verhoeffiella);* and from *Alloscopus* and *Heteromurtrella* by the lack of macrochaetae on Abd. 1 of adult *Heteromurus* s. str. and by the absence of head seta S_0 in members of the nominal subgenus. In addition, *Alloscopus* and *Heteromurtrella* are strictly tropical.

[2]*The system for naming head setae was proposed by Mari Mutt (1979b) and is detailed therein.*

Geographic Distribution. The subgenus is essentially holarctic with most species living in Europe. Figure 33 presents the distribution of *H. major* and *nitidus;* the range of all but one of the other species falls within these.

Key to Species

1. Inner margin of tibiotarsi with rows of smooth setae; eyes 2&2, 1&1 or absent 2

   Tibiotarsi without smooth setae (with exception of seta opposite tenent hair of metathoracic legs, which is present throughout subfamily); eyes 8&8 or 3&3 4
2. Th. 2 (Fig. 22) with 6 posterior setae; head and body with many microchaetae and few scales; scales absent from Ant. 3 and legs; ungues (Fig. 26) very long, about 3.3x width of tibiotarsus at level of tenent hair; antennae long, 0.6-0.8x length of head and body combined; caves in northern Algeria . . . . . *peyerimhoffi* Denis 1937

   Th. 2 (e.g., Fig. 5) with 4 posterior setae; head and body with few microchaetae and many scales; scales on Ant. 3 and legs; ungues shorter, about 2.5x width of tibiotarsus at level of tenent hair (Fig. 31); antennae shorter, 0.4-0.5x length of head and body combined 3
3. Apical mucronal tooth greatly elongated (Fig. 17); eyes absent; scales opaque, gray; Romanian cave . . . . . *noseki* Mari Mutt and Stomp 1980

   Mucro normal; eyes 2&2, 1&1 or absent; scales hyaline or opaque; if opaque, light to dark brown; geographic distribution as in figure 33 . . . . . *nitidus* (Templeton) 1835
4. Eyes 3&3; venter of head mostly with smooth setae; dorsum of manubrium with smooth setae; differentiated seta of outer labial papilla clearly surpassing apex of its papilla (Fig. 16); Middle East and Mediterranean region . . . . . *sexoculatus* Brown 1926

   Eyes 8&8; venter of head mostly with ciliated setae; dorsum of manubrium without smooth setae; differentiated seta of outer labial papilla at most reaching apex of its papilla, usually not so long (Fig. 4, 10) 5
5. Labral papillae of type II (Fig. 11); seta E(L_2 in original description) of labial triangle most often ciliated Fig. 12); all other setae of posterior labial row ciliated; USSR (Tajikistan) . . . . . *variabilis* Martynova 1974

   Labral papillae of type III (Fig. 18-19) or absent; seta E of labial triangle smooth; at least 1 other seta of posterior labial row also smooth 6
6. Labral papillae of type III (Fig. 18-19); length of adults up to 5.0 mm; individuals over 2.3 mm with scales on base of labium (see Mari Mutt and Stomp 1980); pigment scarce, very light, restricted to Ant. 4-5; Portugal . . . . . *gigans* Mari Mutt and Stomp 1980

   Labral papillae absent; length of adults up to 3.0 mm, most frequently up to 2.5 mm; scales absent from base of labium; pigment more abundant (Fig. 2, 3), seldom restricted to Ant. 4-5; geographic distribution as in figure 33 . . . . . *major* (Moniez) 1889

Descriptions

Note: The literature on *H. nitidus* and *major* is too extensive to be listed here. Up to early 1978 the first species was mentioned in 626 publications and the second in 125. All these references are detailed by Mari Mutt (1978b). A large number of references published before 1961 are listed by Salmon (1964). I have detailed herein, for the aforementioned names, their full synonymy and those references considered more relevant. Full synonymy and all the references are included for the other species except for some papers by Zonev, dealing with *H. sexoculatus*, which I have not obtained.

Heteromurus (Heteromurus) major (Moniez)

Templetonia major Moniez 1889: 26-27. Moniez 1890: 68-69.
Heteromurus major (Moniez). Absolon 1901: 11-12. Börner 1901: 76-78, pl. 2, Fig. 9. Denis 1923: 56-57. Denis 1924: 276-280. Handschin 1942: 425-428, 443, 445.

Stach 1967: 394, 409-411, pl. 33. Hüther 1970: 8-9, Fig. 22-28. Ellis 1974: 123-124. Martynova, Chelnokov and Rasulova 1974: 66, 67. Ellis 1976: 310.

Ptenura major (Moniez). Salmon 1964: 479.

Heteromurus caerulescens Börner 1903: 156. Denis 1925: 212. Salmon 1954: 122. Mari Mutt 1980: 544.

Ptenura caerulescens (Börner). Salmon 1964: 479.

Heteromurus melitensis Stach 1924: 115, pl. 1, Fig. 13, Stach 1967: 409, 410, 411.

Ptenura melitensis (Stach). Salmon 1964: 479.

Heteromurus mexicanus Handschin 1928: 545. NEW SYNONYMY.

Ptenura mexicana (Handschin). Salmon 1964: 479.

Heteromurus caucasicus Chelnokov 1974: 70, 71; in Martynova, Chelnokov and Rasulova 1974. NEW SYNONYMY.

Lepidocyrtus lundbladi Agrell 1939: 5-6. Gisin 1948: 125. Gama 1959: 33. Gama 1961: 14, 15.

Habitus as in figures 2 & 3, see also Stach 1967: plate 33, Fig. 1 and Stach 1924: plate 1, Fig. 13 (as *melitensis).* Length up to 3.0 mm, generally up to 2.5 mm. Coloration variable; typical pattern (Fig. 2) composed of pigment distributed throughout antennae (more conspicuous on Ant. 3-5), anterior and lateral portions of head, anterior ⅓ of mesonotum, lateral margins of Th. 2 - Abd. 1, and throughout legs, especially on femora and tibiotarsi; light pigment sometimes along borders of body segments. Lighter and darker (Fig. 3) individuals, as well as all intergrades, may occur sympatrically. Antennae about 0.4x length of head and body combined. Eyes 8&8 on dark patches, eyes g&h reduced in diameter (Fig. 7). Labral papillae absent (see Stach 1967: plate 33, Fig. 2). Chaetotaxy of labial triangle (Fig. 6, see also Martynova et. al. 1974: 67, Fig. 1 and Huther 1970: 10, Fig. 27) variable, A_1, A_2 and E smooth; posterior row with 4-6 ciliated setae or 1 (seldom 2) smooth setae. Differentiated seta of outer labial papiilla short, slender, not reaching apex of its papilla (Fig. 4). Setae of PLQ and most other setae on venter of head ciliated. Tibiotarsi without smooth setae. Ungues quadridentate (Fig. 8), seldom tridentate. Unguiculus with small outer tooth. Tenent hair apically clavate. Body macrochaetotaxy typical of subgenus (Fig,. 5, see also Huther 1970: 10, Fig. 22). Furcula without smooth setae. Mucro with basal spine.

Comments. Although it is preferable not to propose new synonyms unless specimens of the taxa concerned are studied, it is my opinion that the name *H. caucasicus* should not have been proposed. According to its author, *caucsicus* is to be separated from *major* by its pigmentation, size, and labial chaetotaxy. The expression of all these characters in *caucasicus* falls within the range of variability of *major. H. caucasicus* was apparently described from a single specimen.

I have received from Dr. F. Bonet ten specimens of *Heteromurus* from near the type locality of *H. mexicanus* Handschin 1928. The specimens agree in most respects with Handschin's description and in all but one aspect with the description of *major* (Mexican specimens are light blue and more evenly pigmented). The original description of *mexicanus,* which did not include diagnosis, presents a color pattern more like that of typical *major* than seen in Bonet's specimens.

The synonymy between *H. major* and *caerulescens* has been proposed several times but frequently preceded by a question mark (e.g., Handschin 1942, Gisin 1960). I have studied a paratype of *caerulescens,* deposited at the BMNH, and can find no difference between it and *major.* As Denis (1924: 279-280) pointed out, *caerulescens* was described at a time when the identity was not clear; Borner (1901) having misconceived Moniez's species. The main difference between both species, according to Borner's description, is the presence of 8&8 eyes in *caerulescens.* Denis (1924) studied the types of *major* and found 8&8 eyes.

Material Examined. JB: FRANCE, Provenze, May 1977, J.A. Barra, col., 27 specimens. MNHN: FRANCE, Boungta-Reine, Seine, Feb. 4, 1945, over 70 specimens. PAS: BULGARIA, Ost. Rica, 850 Bistrica, April 18, 1936, L. Drenowski, col., 8 specimens. BULGARIA, Warna, Aug. 20, 1937, L. Drenowski, col., 4 specimens. HUNGARY, south of Budapest, Simontornya, Kom. Tolna, 24 specimens. MALTA, 1925, Gatto, col., 35 specimens (identified as *H. melitensis* by Stach). WNE (all collected by W.N. Ellis): FRANCE, var. Gossin, April 29, 1975 (1975-076), 1 specimen. FRANCE, van Gorge de Verden, April 26, 1975 (1975-004), 3 specimens. SPAIN, Mallorca, Arta, Feb. 2, 1975 (1975-004), 2 specimens. As preceding but Lluch Alcami, Nov. 11, 1975

(1975-279), 2 specimens. GREECE, Crete, Knossos, Oct. 24, 1972 (1972-242, see Ellis 1976: 223 for full locality data), 2 specimens. As preceding but 1972-195, 1 specimen. Drosia, Oct. 23, 1972 (1972-226), 1 specimen. Rhodes, Lindhos, April 15, 1970 (1970-010, see Ellis 1974: 107 for full locality data), 3 specimens. Kalathos, April 5, 1970 (1970: 022, 2 specimens.) INHS. MEXICO, Federal District, Aug. 15, 1953, A. Barrera, col., 10 specimens identified as *H. mexicanus* by Bonet. Also in the INHS are several specimens from some of the localities listed above. JAMM. Some specimens from the above localities.

The present author has no information about the whereabouts of the types of this species.

Geographic Distribution (Fig. 33): Known from one or more localities in the following countries: Algeria (north), Austria, Bulgaria, Chile (Mallueco Province, 36-40° s. lat.), Czechoslovakia, France (mainland, Yeu, Corsica), Germany, Greece (Crete, Rhodos), Hungary, Italy (mainland, Molara, Tavolara, Tuscan Archipielago), Mexico, Palestine Region, Portugal (mainland, Madeira, Azores), Romania, Spain (mainland, Canary Islands, Annobon Island-Gulf of Guinea), Switzerland, USSR (Azerbaijan SSR), Yugoslavia.

Womersley (1934: 472) cites this species from Sierra Leone and Morocco. His records are presented in a table without references and are omitted from the preceding list.

The only records of this species outside Europe and the Mediterranean region are: 1) Annobon Island, Gulf of Guinea (Selga 1962, 1 specimen). This record probably represents an introduction during the colonization by Spain. 2) Chile, Mallueco Province, south of the tropic of Capricorn (Rapoport & Rubio 1968, 1 specimen). This record could represent an introduction to a climate similar to that of the Mediterranean region. 3) Southern Mexico, vicinity of Mexico City (Handschin 1928, as *H. mexicanus* and this paper, see material examined). This record lies in the neartic region and could represent an introduction or remnants of a once wider distribution.

Heteromurus (Heteromurus) variabilis Martynova

Heteromurus variabilis Martynova 1974: 66, 68-70, 71; in Martynova, Chelnokov and Rasulova 1974.

Length to 2.5 mm. Color pattern variable, ranges from heavily pigmented (Fig. 9, see also Martynova et. al. 1974: 68, Fig. 2a) to practically unpigmented individuals (Martynova et. al., *loc. cit.* Fig. 2b). Ant. 1-3 unpigmented; Ant. 4-5 at least lightly pigmented, frequently deeply pigmented creating a striking pattern. Antennae about 0.4x length of head and body combined. Eyes 8&8 on dark patches. Labral papillae of type II (Fig. 11); all papillae similar, short, conelike, apically pointed, unlike type II papillae in subgenus *Heteromurtrella.* Chaetotaxy of labial triangle (Fig. 12) variable; all setae of second row ciliated, seta E (L_2 in original description) most frequently ciliated. Differentiated seta of outer labial papilla as in figure 10. Setae of PLQ and most other setae on venter of head ciliated. Tibiotarsi without smooth setae. Methathoracic claws as in figure 13, basal pair of ungual teeth placed halfway along inner lamellae. Tenent hair apically clavate. Furcula without smooth setae. Mucro with basal spine.

Material Examined. PAS: USSR, Tajikistan, 20 km north of Dushambe, May 18, 1972, in detritus, Paupowski, col., 5 specimens.

Type material (not examined) is deposited at the LSU.

Geographic Distribution (Fig. 33): Known only from Tajikistan, USSR.

Heteromurus (Heteromurus) sexoculatus Brown

Heteromurus sexoculatus Brown 1926: 212, 213-214. Handschin 1942: 428-429. Denis 1948: 49. Gisin 1960: 238. Gruia 1964: 203. Gruia 1969: 165, 166, 167. Ellis 1974: 124. Ellis 1976: 310-311.
Heteromurus major var. *sexoculatus* Brown. Ellis 1974: 124.
Ptenura sexoculata (Brown). Salmon 1964: 483.

Heteromurus hexophthalmus Denis 1948: 48. Delamare Deboutteville 1952: 77. Cassagnau & Delamare Deboutteville 1955: 383. Gisin 1960: 238. NEW SYNONYMY.
Ptenura hexophthalma (Denis). Salmon 1964: 479.

Length to 2.1 mm. Pigment restricted to eye patches. Antennae not over 0.4 x length of head and body combined. Eyes 3&3 on characteristic patches (Fig. 14, 15). Labral papillae absent. Chaetotaxy of labial triangle variable; posterior row with 2-4 setae, all of which may be smooth or ciliated. Diffentiated seta of outer labial papilla as in figure 16. Setae of PLQ and other setae on venter of head smooth except for few ciliated setae ventro-laterally on head. Tibiotarsi without smooth setae. Ungues tri-or quadri-dentate (Fig 20); unguiculus with small outer tooth (not mentioned in original description). Tenent hair apically lanceolate or clavate. Manubrium dorsally with at least 4 pairs of smooth erect setae (Fig. 21); base of dentes dorsally with 1 pair of these setae. Mucro with basal spine.

Comments. It is with some hesitation that I have synonymyzed *H. hexophthalmus* to *sexoculatus*. That both ''species'' are close can be gathered from one of Deni's (1948: 48) statements on the relationship between his new species and *sexoculatus: ''Ces differences sont plus que suspectes et la reunion des deux especes est possible''*. The main difference is the shape of the eye patch; in *sexoculatus* all eyes are surrounded by pigment (Fig. 14) but in *hexophthalmus* the patch is divided in two (Fig. 15).

I have studied French specimens identified as *H. hexophthalmus* and specimens from Rhodos and Crete called H. sexoculatus (Ellis 1974, 1976). Besides the aforementioned difference, all *hexophthalmus* have only smooth setae on the labial triangle (smooth and ciliated setae in *sexoculatus),* and all ungues are tridentate (quadridentate in *sexoculatus).*

It is tempting to separate both species but there is no assurance that Ellis' specimens are really *sexoculatus* (the types of *sexoculatus* are apparently lost, see Ellis 1976: 311). The original description of Brown's species and the redescription by Handschin (1942) figured lanceolate tenent hairs and tridentate ungues like *hexophthalmus* at hand. The relative position of the eyes of *sexoculatus* (Brown 1926: 212, Fig. 25) is also as in *hexophthalmus* under study. If two species with 3&3 eyes are present, a new name may have to be proposed for Ellis' specimens while retaining *sexoculatus* and *hexophthalmus* a synonyms.

Material Examined. MNHH: FRANCE, 27 Tuzet, Terreau Nimes Gird, maisson deyrolle, 10 specimens. 12 Tuzet, 1 specimen (all the preceding specimens are identified as *hexophthalmus).* WNE: GREECE, Rhodes, Lindhos, April 10, 1970, soil sample of moderately damp, crumbly loam, in a shadowed olive garden (1970-006), W.N. Ellis, col., 1 specimen. Crete, Festós, along Geropotamus, Oct. 16, 1972, rather dry crumbly loam with many roots and stones in a small bush along Geropotamus, consisting of *Vitis, Punica* and *Ficus;* with little undergrowth of geophytes (1972-227), W.N. Ellis, col., 1 specimen. All Greek material was identified as *sexoculatus* by Ellis.

Geographic Distribution: As *sexoculatus*-Mesopotamia (Iraq), Palestine region, Greece (Central Crete, Rhodos), Romania (caves). As *hexophthalmus*-France, Lebanon.

Heteromurus (Heteromurus) peyerimhoffi Denis
Heteromurus peyerimhoffi Denis 1937: 87. Gisin 1960: 239. Stomp 1974: 112-113.
Ptenura peyerimhoffi (Denis). Salmon 1964: 483.

Length to 2.7 mm. Pigment restricted to eye patches. Scales absent from Ant. 3-5, legs, and collophore. Ant. 1-2 with few (1-4) scales, manubrium scaled sparsely. Scales hyaline, apically rounded or tuncated, not fusiform. Microchaetae abundant throughout antennae, dorsum of head and body, legs, and furcula. Antennae long, about 0.6-0.9x length of head and body combined. Ant. 5 annulated, Ant. 4 not annulated but most dorsal setae arranged in whorls. Eyes 2&2 on small dark patch. Labral papillae absent. Chaetotaxy of labial triangle as in figure 24, all setae smooth. Differentiated seta of outer labial papilla long (Fig. 25). Setae of PLQ and most other setae on venter of head smooth. Tibiotarsi with double or triple row of smooth setae along inner margin. Femora with some smooth setae. Ungues (Fig. 26) unusually long, slender, with a pair of short basal teeth. Unguiculus with very small outer tooth. Tenent hair short, apically lanceolate. Body macrochaetotaxy typical of subgenus except for posterior half of Th. 2 (Fig. 22). Dorsum of manubrium with smooth setae arranged as in figure 23. Mucro with inconspicuous basal spine,

apical mucronal tooth markedly longer than subapical.

Comments. This species stands no chance of confusion with any other member of the subgenus. Its claw structure reminds of *H. (Verhoeffiella) hispanicus* and *H. (V.) longicornis* but the presence of eyes and nonannulated Ant. 4 separates the species from members of that subgenus.

Other diagnostic features, aside from claw structure, are the chaetotaxy of Th. 2, presence of many microchaetae on head and body, number and arrangement of smooth setae on dorsum of manubrium, and the long antennae.

Material Examined. NS: ALGERIA, Djurdjura, glacial caves, on snow, 2 °C., summer of 1972, F. Delhez, col. (locality no. 2 in Stomp 1974: 113), 6 specimens. As preceding but P13, 15, 17; Petit Bousoil cave, 17 specimens. INHS, JAMM: 2 specimens each from the second locality.

Type material (not seen) should be at the MNHN.

Geographic Distribution: Algeria, known only from the glacial caves of Djurdjura.

Heteromurus (Heteromurus) nitidus (Templeton)

Podura nitida Templeton 1835:94.

Ptenura nitida (Templeton). Templeton 1844: 306. Salmon 1945: 71. Salmon 1964: 131-132, 478, 480-483.

Isotoma nitida (Templeton). Nicolet 1847: 375. Kolenati 1858: 133 (as *nitidens).*

Templetonia nitida (Templeton). Lubbock 1862: 595, 596. Lubbock 1873: 13, 18, 142, 143, plate 20.

Templetonia (Heteromurus) nitida (Templeton). Theobald 1910: 193.

Beckia nitida (Templeton). McIntire 1873: 5.

Choreutes nitidus (Templeton). Elditt 1854: 20-21.

Heteromurus nitidus (Templeton). Megnin 1888: 261. Absolon 1901: 11, 12. Denis 1924: 280-282. Denis 1931: 12-13. Bonet 1931: 272-276, 283, 284, 350, 354, 356, 387. Mills 1934: 77. Denis 1934: 93-96. Denis 1935: 343-344. Delamare Deboutteville 1944: 29-30. Gisin 1944: 90, 97. Maynard 1951: 179, 184-185, 189. Yosii 1961: 26. Szeptycki 1972: 341, 342, 359, 364, 371, 372. Szeptycki 1979: 14, 19, 20, 36, 37, 49, 55, 56, 57, 59, 72, 73, 81, 85, 88, 83, 136, 137, 154, 164, 171, 187, 190, 198, 199.

Heteromurus (Heteromurus) nitidus (Templeton). Strouhal 1939: 263. Grindbergs 1960: 51.

Heteromurus (Heteromurus) nitidus margaritarius (Templeton). Grindbergs 1960: 51.

Heteromurus nitidus margaritarius (Templeton). Stach 1929: 295. Gruia 1976: 95, 101.

Heteromurus nitidus margaritaceus (Templeton). Paclt 1957: 273.

Heteromurus nitidus paucidentatus Stach 1929: 295. Gruia 1976: 90, 101.

Heteromurus nitidus quadriocellata Kseneman 1934: 14-15, 20. Gisin 1960: 239. Gruia 1976: 100.

Heteromurus nitidus albicans Durkop 1934: 508.

Heteromurus nitidus brevicornis Bonet 1934: 180-182, 185.

Heteromurus nitidus armapollerae Massera 1952: 32-33. Gilsin 1960: 239.

Heteromurus margaritarius Wankel 1860: 203. Absolon 1900a: 191, 192. Paclt 1972: 414. Bellinger & Ellis 1972: 213.

Heteromurus (Templetonia) margaritarius Wankel. Absolon 1900a: 192. Absolon 1901c: 12.

Degeeria margaritacea Nicolet 1842: 75.

Heteromurus hirsutus Absolon 1899a: 317. Absolon 1899b: 493, 495-496. Absolon 1901c: 8-12, plate 1. Cassagnau & Delamare Deboutteville 1955: 367. Paclt 1972: 414.

Ptenura hirsuta (Absolon). Salmon 1964: 479.

Heteromurus tetrophthalmus Börner 1903: 156. Stach 1922: 109, 122. Denis 1930: 94 (as *tatraphthalmus).* Gisin 1944:97. Gisin 1960: 239. Stomp 1974: 109-113, 114. NEW SYNONYMY.

Ptenura tetrophthalma (Börner). Salmon 1964: 483.

Heteromurus cavernicolus Ionesco 1915: 222. Bonet 1931: 353.

Heteromurus gradgensis Denis 1933: 212. Denis 1934: 93. Denis 1935: 331. Denis 1936: 263-265. Denis 1938: 145. Gisin 1960: 239.
Podura crystallina Müller 1776: 183.
Isotoma crystallina (Müller). Parona 1878: 584.
Heterotoma crystallina (Müller). Bourlet 1839: 396. Gervais 1844: 377.
Orchesella crystallina (Müller). Nicolet 1847: 366.
Templetonia crystallina (Müller). Lubbock 1873: 143.
Aetheocerus crystallinus (Müller). Bourlet 1842: 32.
Sinella cavernicola Carpenter 1895: 30.
Templetonia cavernicola (Carpenter). Carpenter 1897: 229. Absolon 1901c: 11, 12, 13.
Templetonia americana Harvey 1892: 57. Mills 1934: 77.
Heteromurus americanus (Harvey). Absolon 1901: 12.
Lepidocyrtus marmoratus Packard 1873: 36. Mills 1934: 77. Gisin 1960: 239.
Pseudosinella kemneri Agrell 1936: 27. Gisin 1944: 155. Gisin 1948: 125. Gisin 1960: 239.
Propemesira duoculata Salmon 1942: 59. Salmon 1945: 71.
Troglosinella clayae Salmon 1955: 25. Gisin 1960: 239. Salmon 1964: 482.

Habitus typical of subgenus (see Lubbock 1873: plate 20 (color) and Delamare Deboutteville 1955: 454, Fig. 1-photograph). Length to 3.0 mm. Pigmentation variable, typical pattern of orange pigment distributed more or less evenly throughout head and body. Pigment sometimes absent or restricted to eye patches, which may be orange or black. Antennae about 0.4x length of head and body combined. Eyes 2&2, 1&1 or absent. Head macrochaetotaxy (Fig. 28) typical of subgenus. Labral papillae absent. Chaetotaxy of labial triangles as in figure 29; all setae smooth, posterior row (excluding E) of 3-4 setae. Differentiated seta of outer labial papilla long, clearly surpassing apex of its papilla (Fig. 30). All setae of venter of head (including PLQ) smooth. Tibiotarsi with 2 rows of strong smooth setae along inner margin, number of setae increases with size of specimen. Ungues (Fig. 31) bi-, tri-, or quadridentate; most often tridentate. Unguiculus usually with well developed tooth beyond middle of outer lamella, tooth sometimes absent. Tenent hair apically lanceolate or clavate, both types sometimes on same specimen. Dorsum of manubrium with double row of smooth erect setae, 1 pair of these setae on proximal dorsal portion of dentes. Mucro sometimes without basal spine.

Comments. Although this species is quite variable with respect to some characters (e.g., pigmentation, number of eyes, number of teeth on unguis and unguiculus, shape of tenent hair) other features are constant and permit rapid recognition. The *nitidus* group of species is characterized by: only smooth setae on labial triangle and rest of venter of head, double row of smooth setae along inner margin of tibiotarsi and the presence of smooth setae on dorsum of manubrium. From *H. peyerimhoffi, nitidus* can be readily separated by the ratio of length of unguis to width of tibiotarsus at level of tenent hair. From *noseki* it can be separated immediately by the shape of the mucro.

The use of latinized names for varieties is undesirable and incorrect since such names are intended for subspecies which by definition must be geographically isolated. None of *H. nitidus'* seven varieties (a key to which is given by Gisin 1944) can be considered as subspecies. Bonet (1931) found specimens of the varieties *quadriocellata* (2&2 eyes), *margaritarius* (eyes absent) and of the nominal variety (1&1) within the same colony. I have found specimens with bidentate *(paucidentata)* and tridentate (nominal variety) ungues in the same population. Similar observations were made by Delamare Deboutteville (1944), Denis (1924, 1931) and Gama (1962). The name *Heteromurus nitidus callaticola* Gruia 1965 (again cited by the same author in 1969) is unavailable as it violates article 45 c, e of the Rules of Zoological Nomenclature which declares unavailable latinized names proposed for varieties after 1960.

Although *H. tetrophthalmus* has been mentioned in 28 publications (17 of which cite new records), the only comprehensive description of the species is the original one (Stach 1922 and Stomp 1974 added descriptive notes). This situation probably arose because the only difference

between *tetrophthalmus* and *nitidus* (e.g., see Gisin 1944, 1960) is the absence of the unguicular tooth in *tetrophthalmus*.

I have studied a paratype of *tetrophthalmus* (kept in the BMNH) and it complies with Borner's description. Some of the specimens recorded by Stomp (1974) from northern Algeria were also studied and no unguicular tooth was found. Specimens reported by Delamare Deboutteville (1946) from Portugal must be refered to *nitidus* because the unguiculi possess a clear outer tooth. Although *nitidus* and *tetrophthalmus* are troglophilic and the geographic range of the latter falls within the former's, they have not been collected together (or perhaps they have but specimens have received only one name).

Whether Borner's *tetrophthalmus* ought to be considered separate from *nitidus* or not depends on the importance assigned to the absence of the unguicular tooth. Faced with such a variable species as *nitidus* I am treating *tetrophthalmus* as a synonym of *nitidus*. An experimental approach, such as that used by Hale & Rowland (1978) to help distinguish species of the *Onychiurus armatus* group, would be a most welcome contribution towards settling the taxonomic status of *tetrophthalmus*.

Material Examined. BMNH, Germany, Frauenburg, Marburg, July 1901, BM 1907-130, C. Börner det., 3 specimens. CZECHOSLOVAKIA, Pacina Cave, Popovopolje, Herzegowina, Aug. 20, 1937, R.S. Hawes, col., BM 1937-88, 1 specimen. BULGARIA, Temna Docapka, Karlova Regn., Aug.-Sept. 1967, on clay, W. Maxwell, col., BM 296 AB 1899, 1 specimen. SWITZERLAND, Chateau du Bols, rotten lichenous fallen bark, May 19, 1963, P.N. & B.K. Lawrence, cols., 1849, 1 specimen. GREECE, Crete, Aug. 20, 1967, Birmingham University Speleological Society expedition, BU 110, 1 specimen. GREECE, northwest region, Perama n. Loannine, moss on electric light stalagmite, May 23, 1971, T. Clay, col., 1 specimen. IRELAND, Bantry County, Jan. 28, 1953, under stones in pasture, 178, BM 1953-91, 1 specimen. Clare, Pollnagollum, Gunmana cave, July 7, 1960, pool in pothole, 769, P.N. Lawrence, col., 1 specimen. Clare, near Ballyvaghna, ¼ km west of Newtown Castle, Aug. 5, 1960, ivy humus foot of 6 meter cliff, 742, P.N. Lawrence, col., 1 specimen. HOLLAND, near Amsterdam, edge of Zuider Zee, Aug. 1, 1951, under stones, BM 1951-459, 1 specimen. ENGLAND, Huntshire, Monks Wood, Sould pond, March 14, 1973, on bank of pond, 3147-51, P.N. Lawrence, col., 2 specimens. Surrey, Godston mine, mid-April 1969, BM/832, BM 1969-221, W. Maxwell, col., 1 specimen. Northumberland, Pegswood, water pollution research laboratory, 1967, BM 1968-418, 1 specimen. Cambridge, Feb. 4, 1925, under board in garden, C.H. Jackson, col., 1 specimen. Kent, Chiselhurst caves, Nail Box chalk mine, April 3, 1955, BM 145, P.N. Lawrence, col., 3 specimens. Somerset, Dundry stone mines, near Bristol, dark zone, Ato/10, 2 specimens. Lincolnshire, Fiskerton, water pollution research laboratory, Sept. 20, 1966, BM 1966-418, 1 specimen. ITALY, Palmi (Calabria), under stone in olive grove, April 9, 1902, C. Borner, col., 1 paratype of *H. tetrophthalmus,* BM 1907-130.

HJG: ENGLAND, Surrey, Godston mine, Oct. 17, 1970, on rotton wood, H.J. Gough, col., 5 specimens. Devon, Rockhouse caves, lower central tunnel, Oct. 10, 1970, W.G.R. Maxwell col., 2 specimens. Berkshire, Jealott's Hill, surface of pond, May 26, 1967, 1 specimen. Berkshire, Bradfield, hazel litter, Sept. 27, 1970, W. Wilkinson, col., 1 specimen. South Devon, Badford cave, on surface of pool, March 17, 1974, H.J. Gough, col., 3 specimens. SPAIN, Picos de Europa, Cueva Dobros, 410 m from entry, Aug. 1972, H.J. Gough, col., 4 specimens.

INHS: USA, Iowa, Ames, Sept. 2, 1933, on a cellar, 57 specimens, CANADA, Ontario, Arnprior, Sept., with earthworms on garden bed, Macnamara, col., 9 specimens.

JAB: FRANCE, Grotte de Bartharram, April 6, 1968, 5 specimens. Strasbourg, June 15, 1966, 2 specimens.

KAC: USA, Iowa, Dubuque Co., Dubuque, Billboard cave, 1483, 1 specimen. Maine, York Co., 453, 1 specimen. New York, Columbia Co., 2218, Polk, Norton & Culver, cols., 1 specimen. New York, Jefferson Co., Glenn Park, Labyrinth cave, 1891, 1 specimen.

MNHN: ITALY, Paitone-Brescia, Buco del Frate, Feb. 10, 1940, M. Pavan, col., 53 specimens. PORTUGAL, Lapa de Salgada, A. de Barros Machado, col., 16 specimens identified as *H. tetrophthalmus* by Delamare Deboutteville 1946. Casa de Moura, Cesaride Peniche (d. Lisboa), Aug. 23, 1943, A. de Barros Machado, col., 1 specimen.

NS: FRANCE, Catacoumbes de Paris, J.-M. Thibaud, col., 13 specimens. ALGERIA, Maudabee Mac 3 cave, F. Delhez, col., 5 specimens identified as *H. tetrophthalmus* by Stomp 1974. Ifri Smedane cave (placed on the foot of a mountain, properly said this is not a glacial cave), IS 1, 12 °C., 3 specimens (labeled *H. nitidus* but treated as *H. tetrophthalmus* by Stomp 1974).

NZNM: NEW ZEALAND, Wellington, under the linoleum in a dwelling, D.K. Ross, col., 1 paratype of *Propemesira duoculata* Salmon.

PAS: BULGARIA, Warva, Aug. 20, 1927, L. Drenowski, col., 8 specimens. Magura cave, near Rabisa, Sept. 8, 1948, 10 specimens. SPAIN, Pyrenees, Santa Isabel station cave, Oct. 8, 1935, G. Santander, col., 10 specimens. Pyrenees, Cueva de Santian, Oct. 5, 1935, Stammer, col., 6 specimens.

SAS: CZECHOSLOVAKIA, Moravian Karst, 18K, June 12, 1973, Zacharda, col., 5 specimens.

USNM, ENGLAND, on potatoes intercepted at Philadelphia (USA), Oct. 17, 1952, 52-12594, 11 specimens. HOLLAND, on lily bulbs intercepted at New York, Sept. 26, 1934, no. 28571, 1 specimen. FRANCE, hickory leaf, lot. 36-29776, Aug. 17, 1936, 1 specimen. USA, New York, Rochester, March 30, 1947, under stone, R. Maynard, col., 16 specimens reported upon by Maynard (1951).

The type material for this species is apparently lost.

Geographic Distribution (Fig. 33): Holarctic with exception of one record from Argentina (Bonet 1934, as *H. nitidus* var. *brevicornis),* one from Chile (Rapoport & Rubio 1968), and one from New Zealand (Salmon 1942, as *Propemesira duoculata).*

My collection contains two Peruvian specimens identified as *H. nitidus* by Winter (1963: 509, collection 34a) but they are *H. (Heteromurtrella) schoetti* Denis 1931, species previously known from Costa Rica and Guatemala. Although Winter (1963) recorded *nitidus* from various other localities, it is likely that they are all *schoetti* or another species of the subgenus *Heteromurtrella.*

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Legends for the Figures

1. Phyletic diagram for the species of *Heteromurus* s. str., see text for explanation.

2-8. *H. (H.) major.* 2. Habitus of lightly pigmented specimen. 3. id., more thoroughly pigmented form; both specimens from same population. 4. Outer labial papilla. 5. Body macrochaetotaxy, each dot represents a seta. 6. Chaetotaxy of labial triangle. 7. Arrangement of eyes. 8. Metathoracic claws.

9-13. *H. (H.) variabilis.* 9. Habitus and distribution of violet pigment. 10. Outer labial papilla. 11. Labral papillae. 12. Chaetotaxy of labial triangle. 13. Metathoracic claws.

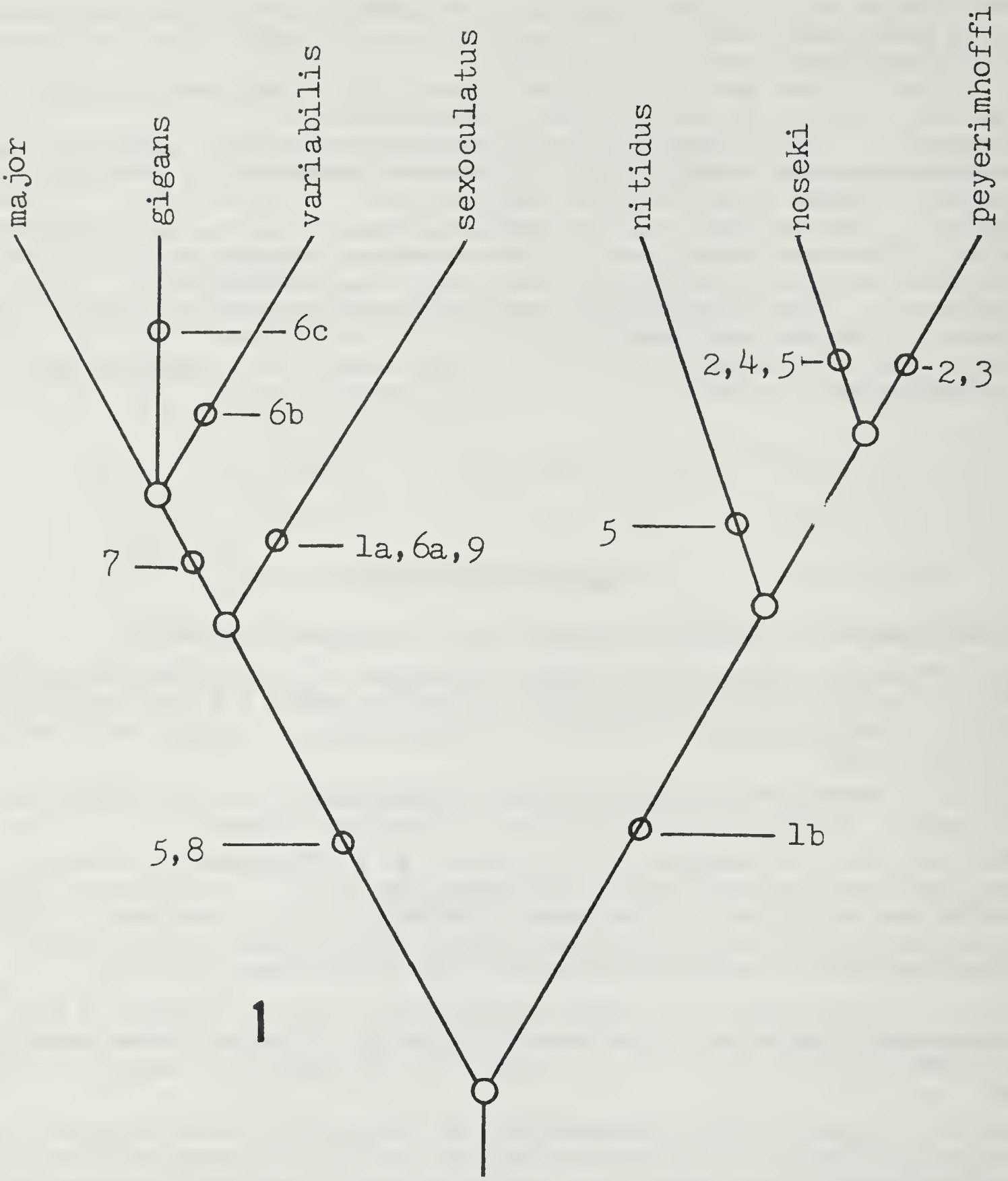
14-16, 20-21. *H. (H.) sexoculatus.* 17. *H. (H.) noseki.* 18-19. *H. (H.) gigans.* 14. Arrangement of eyes of specimen from Crete labeled *H. sexoculatus* (det. Ellis). 15. Arrangement of eyes of specimen from France labeled *H. hexophthalmus* (det. Denis). 16. Outer labial papilla. 17. Mucro. 18. Outer labral papilla, lateral view. 19. Labral papillae. 20. Metathoracic claws. 21. Manubrium and proximal portion of dens showing distribution of smooth erect setae, lateral view.

22-27. *H. (H.) peyerimhoffi.* 22. Body macrochaetotaxy, each dot represents a seta. 23. Manubrium and dorsal portion of dentes detailing distribution of smooth erect setae, dorsal view. 24. Chaetotaxy of labial triangle. 25. Outer labial papilla. 26. Metathoracic claws. 27. Maxillary palp.

28-32. *H. (H.) nitidus.* 28. Head macrochaetotaxy; each dot represents a seta, P = posterior group. 29. Chaetotaxy of labial triangles and positions of setae forming the postlabial triangle (PLQ). 30. Outer labial papilla. 31. Metathoracic claw; unguis may have 2-4 inner teeth, tenent hair may be apically lanceolate or clavate. 32. Chaetotaxy of labial triangle.

33. Geographic distribution of *H. (H.) major, nitidus* and *variabilis.*

Ancestor of HETEROMURUS s. str.



Ancestor of HETEROMURUS s. str.

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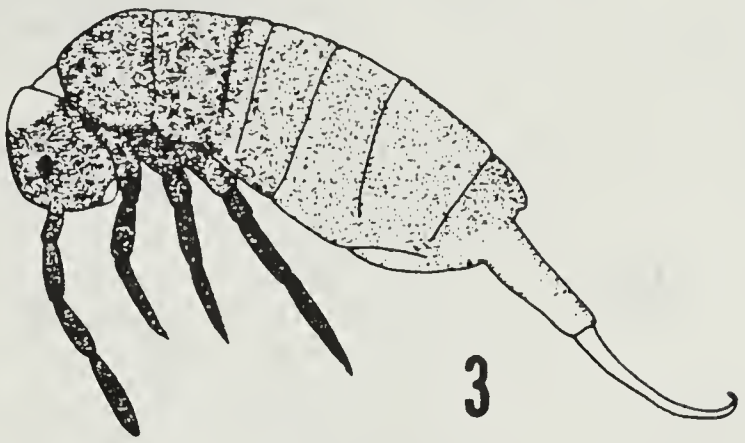

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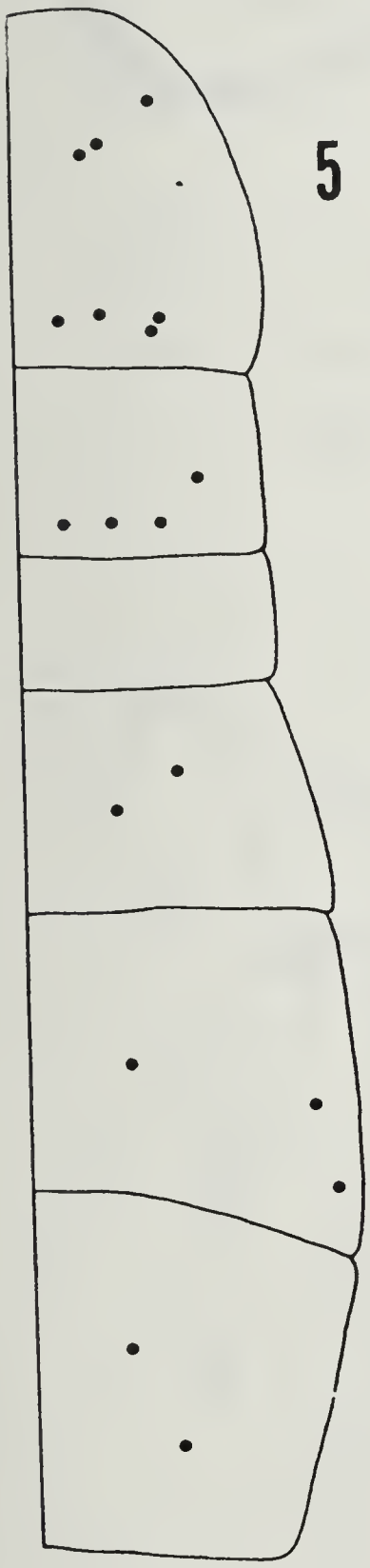

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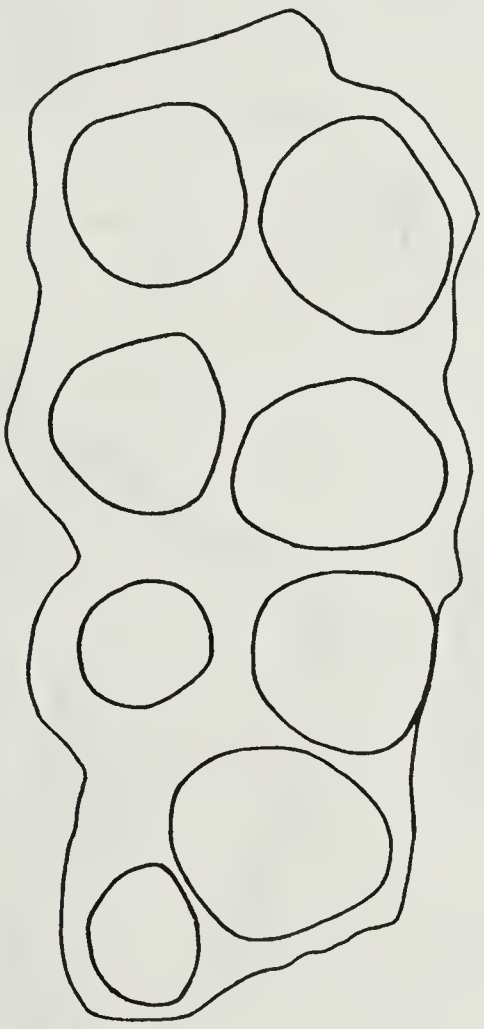

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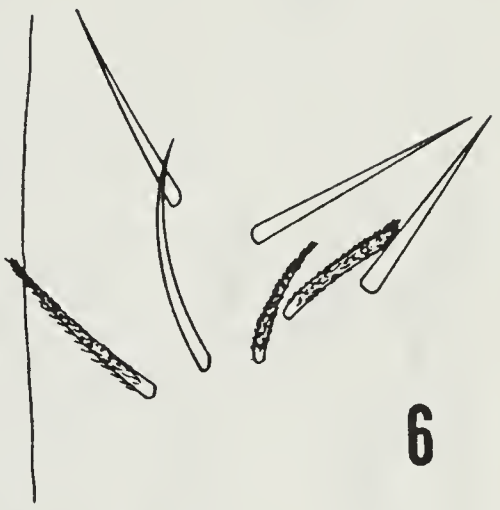

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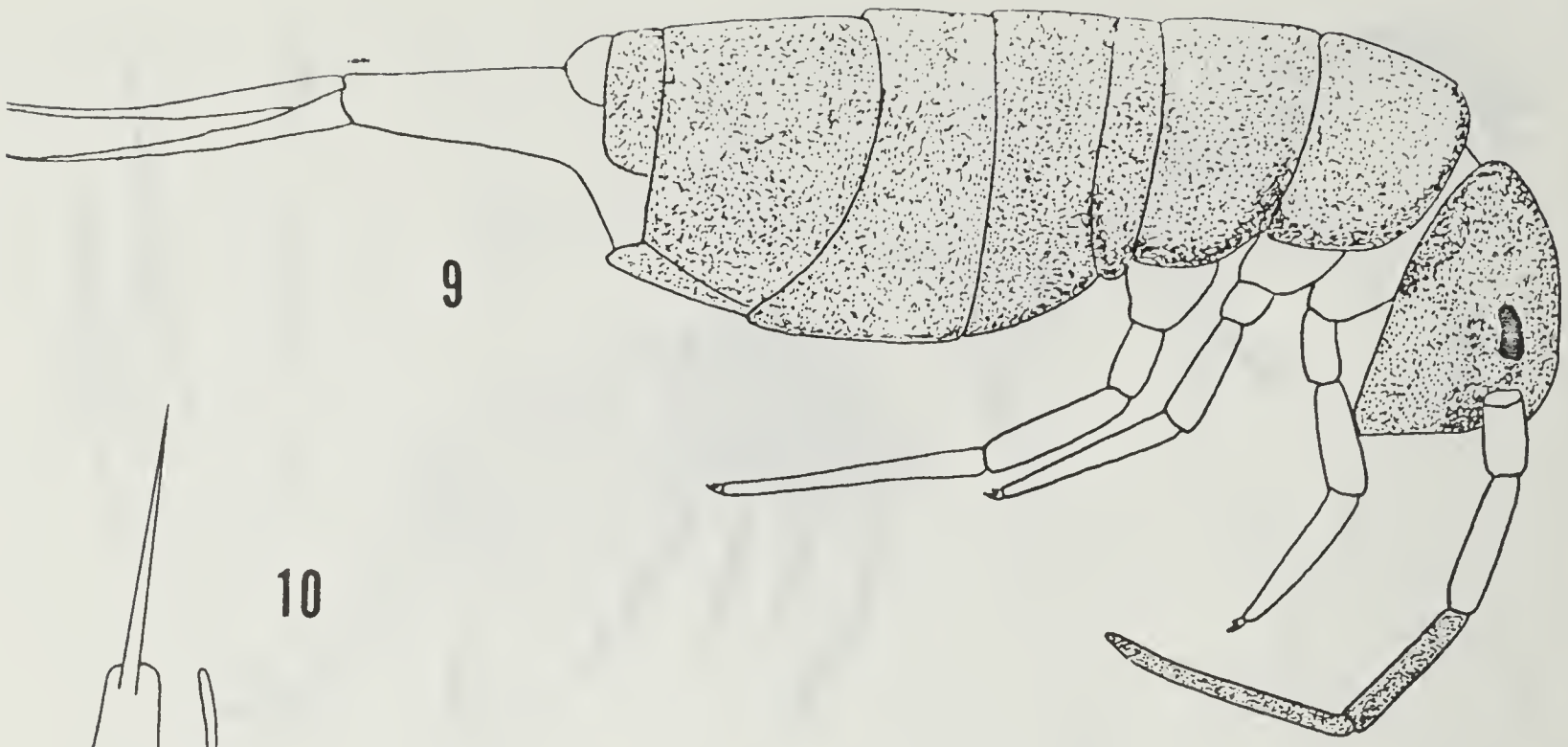

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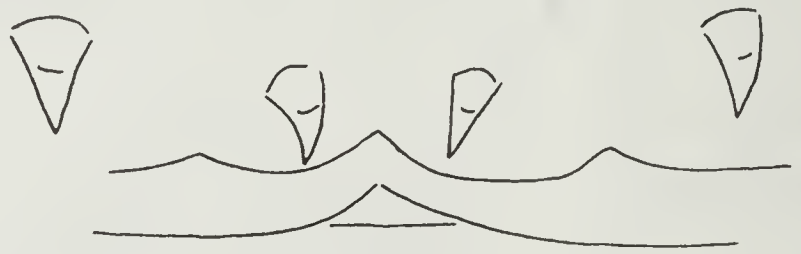

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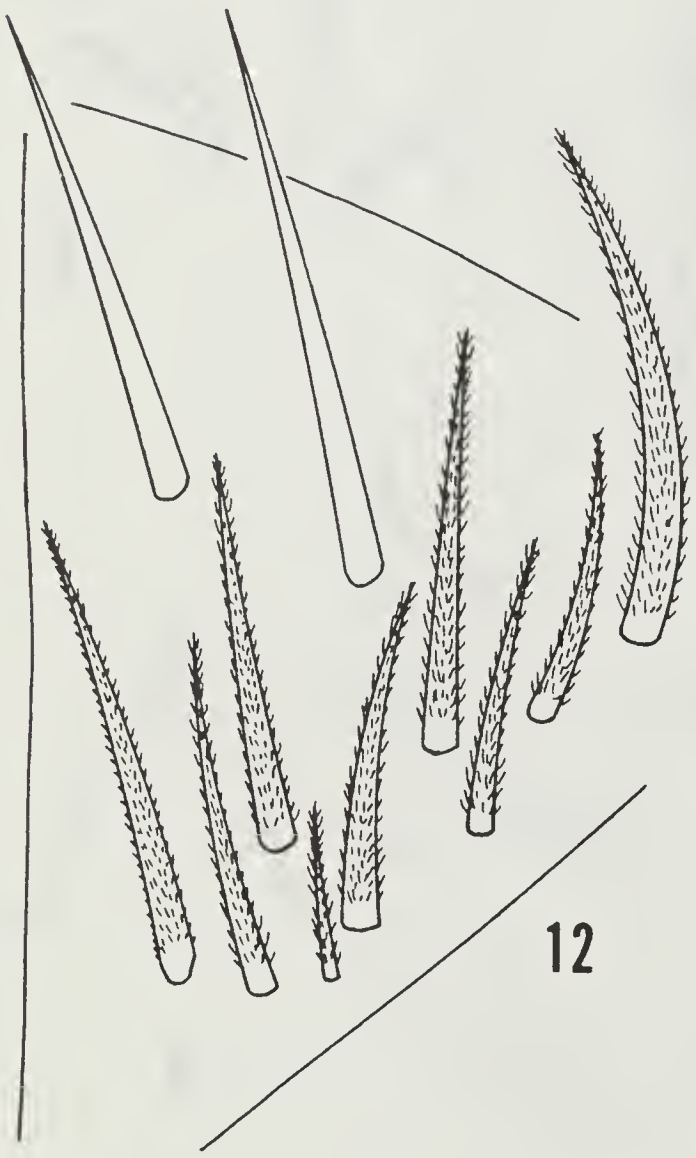

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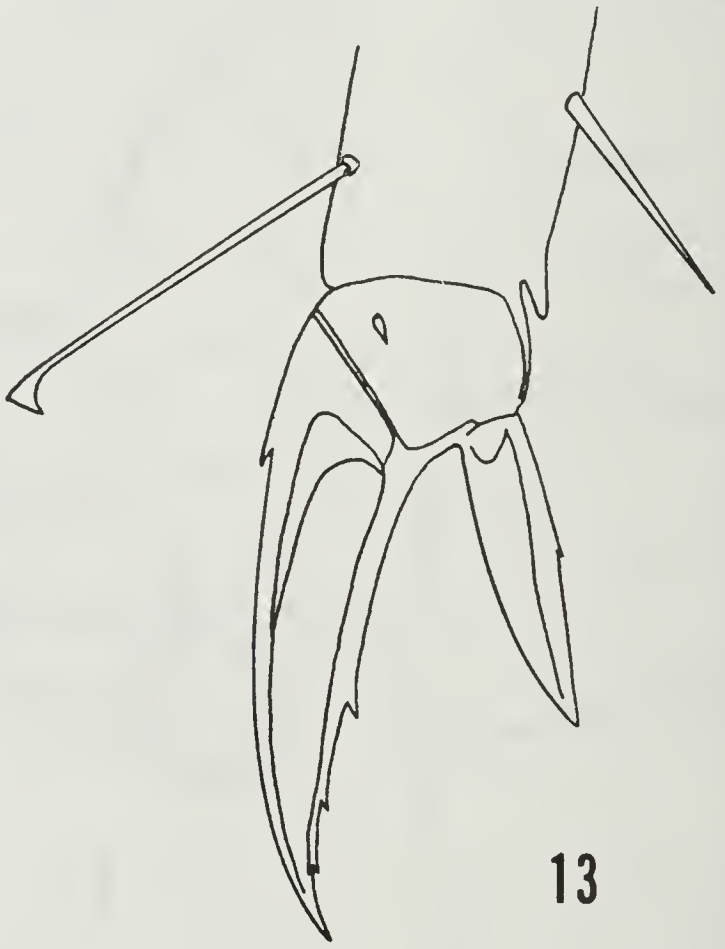

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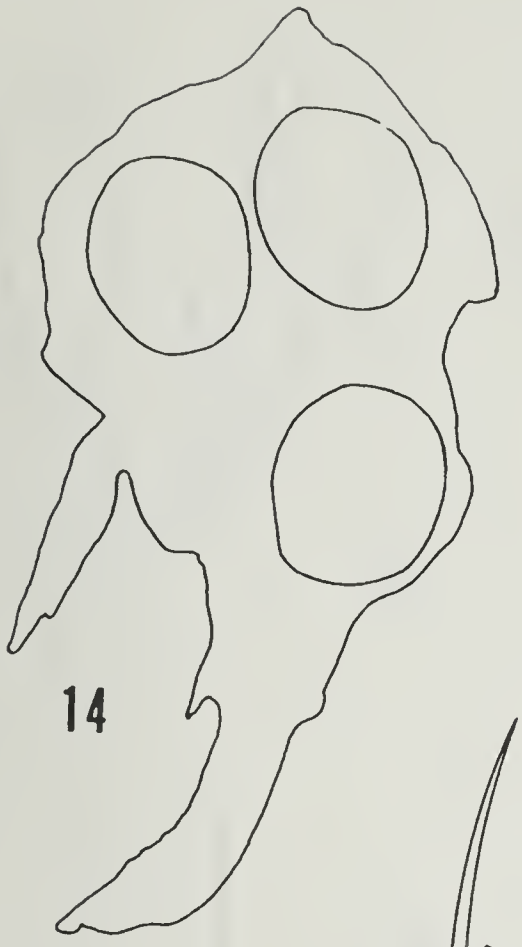

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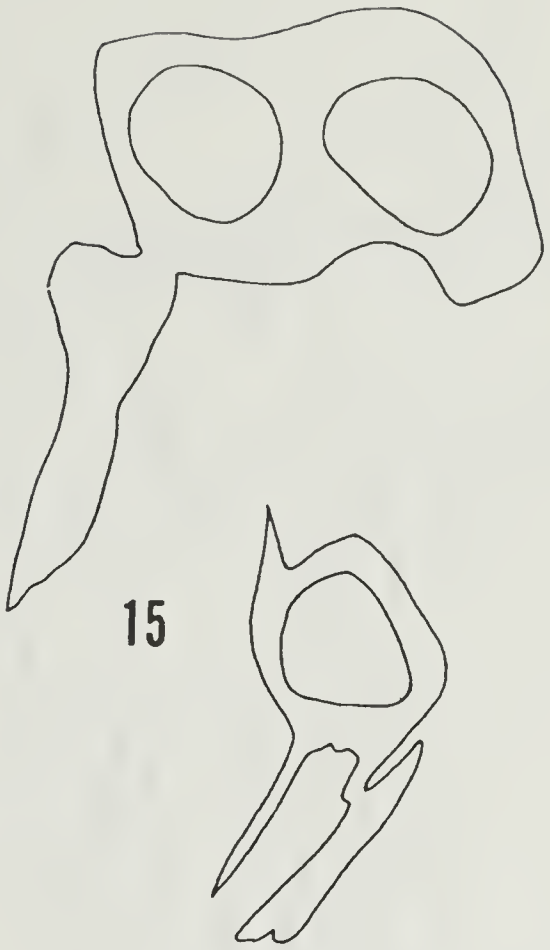

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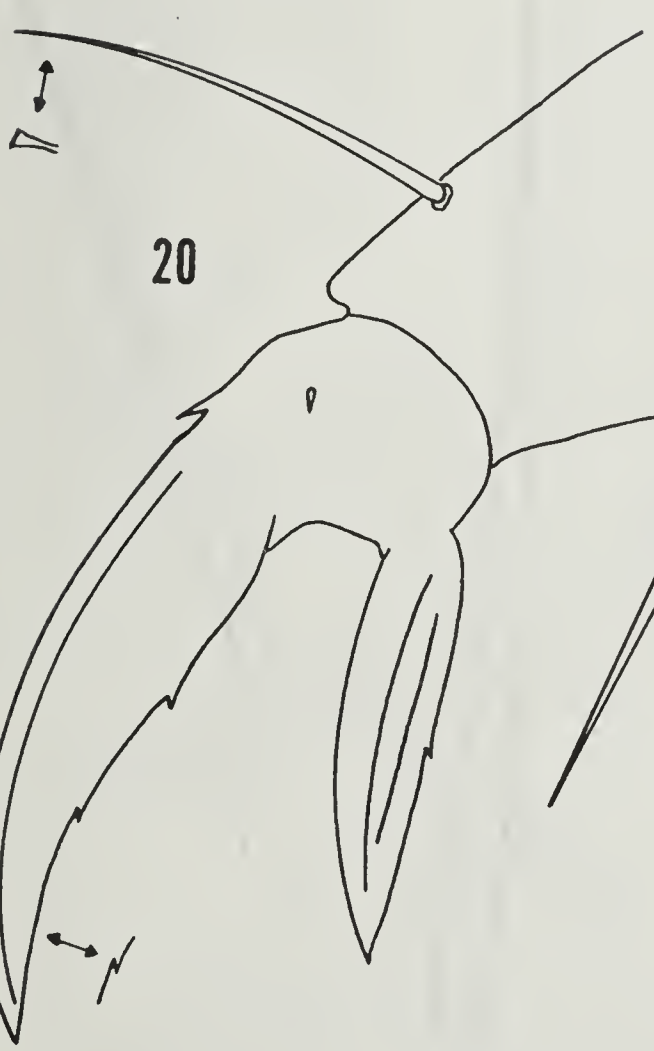

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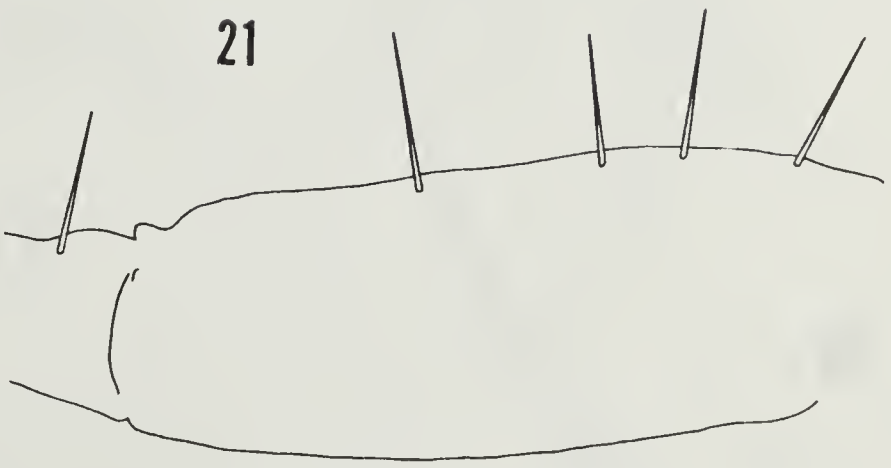

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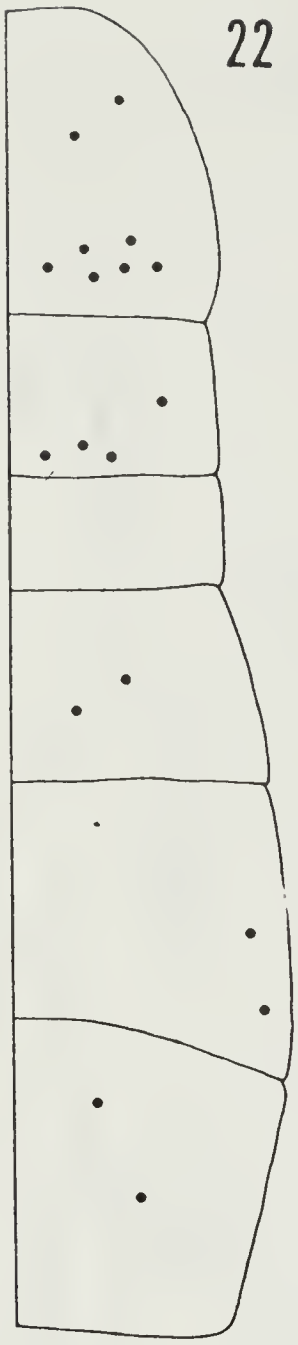

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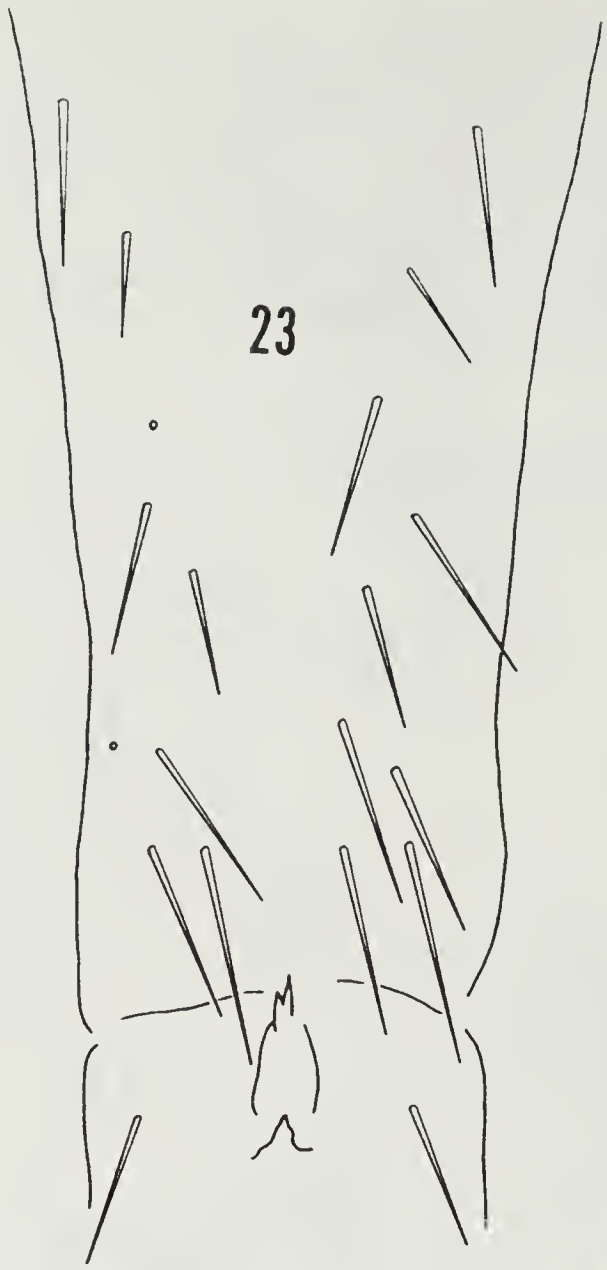

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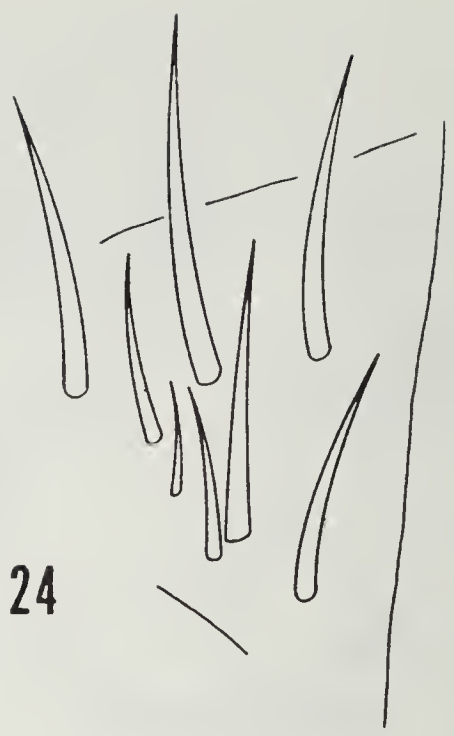

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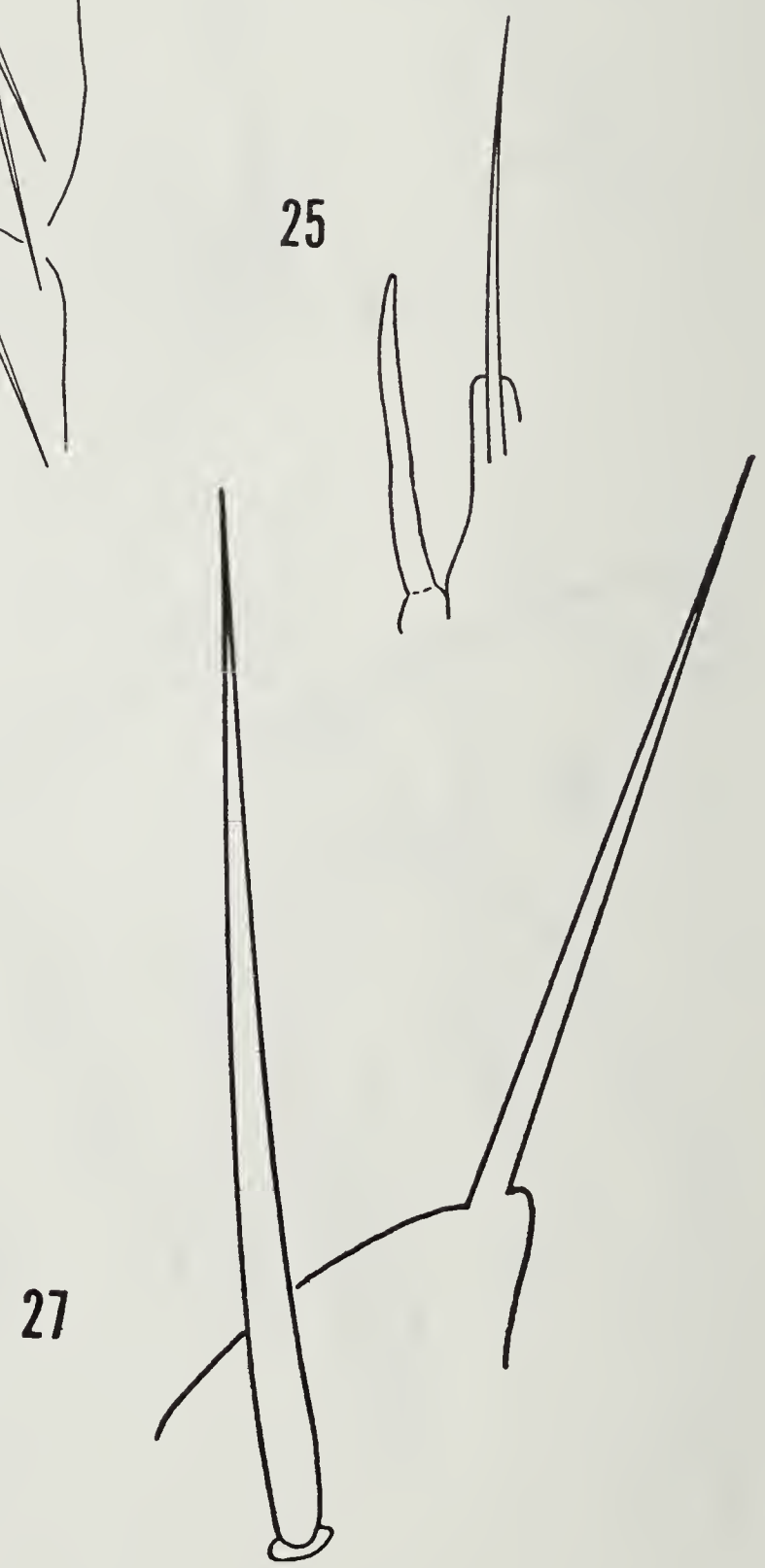

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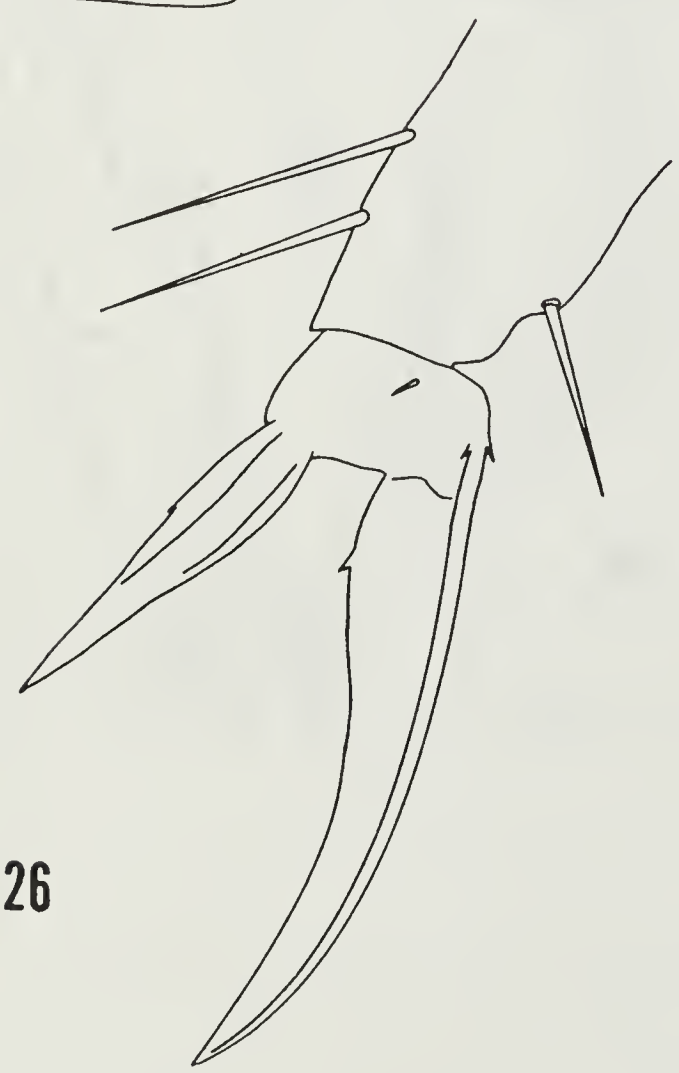

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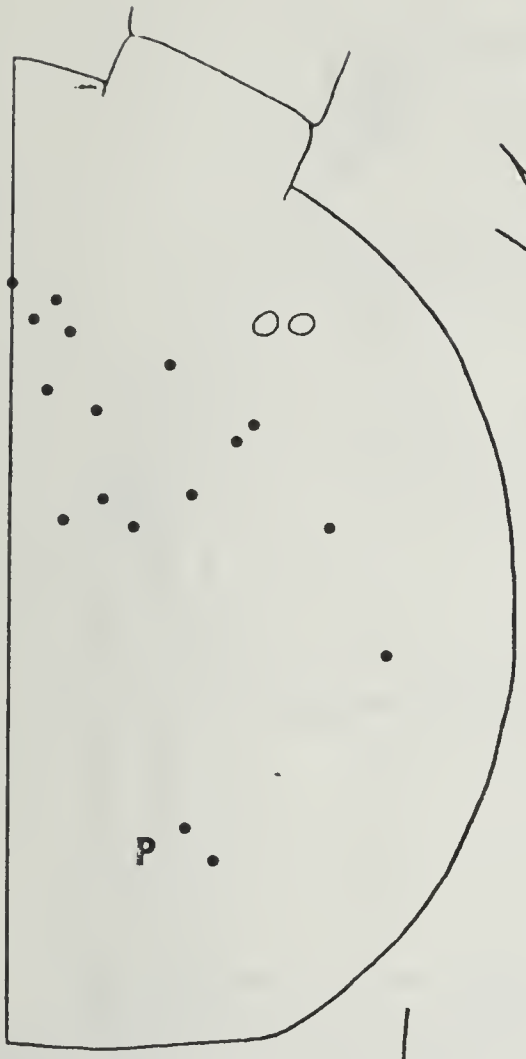

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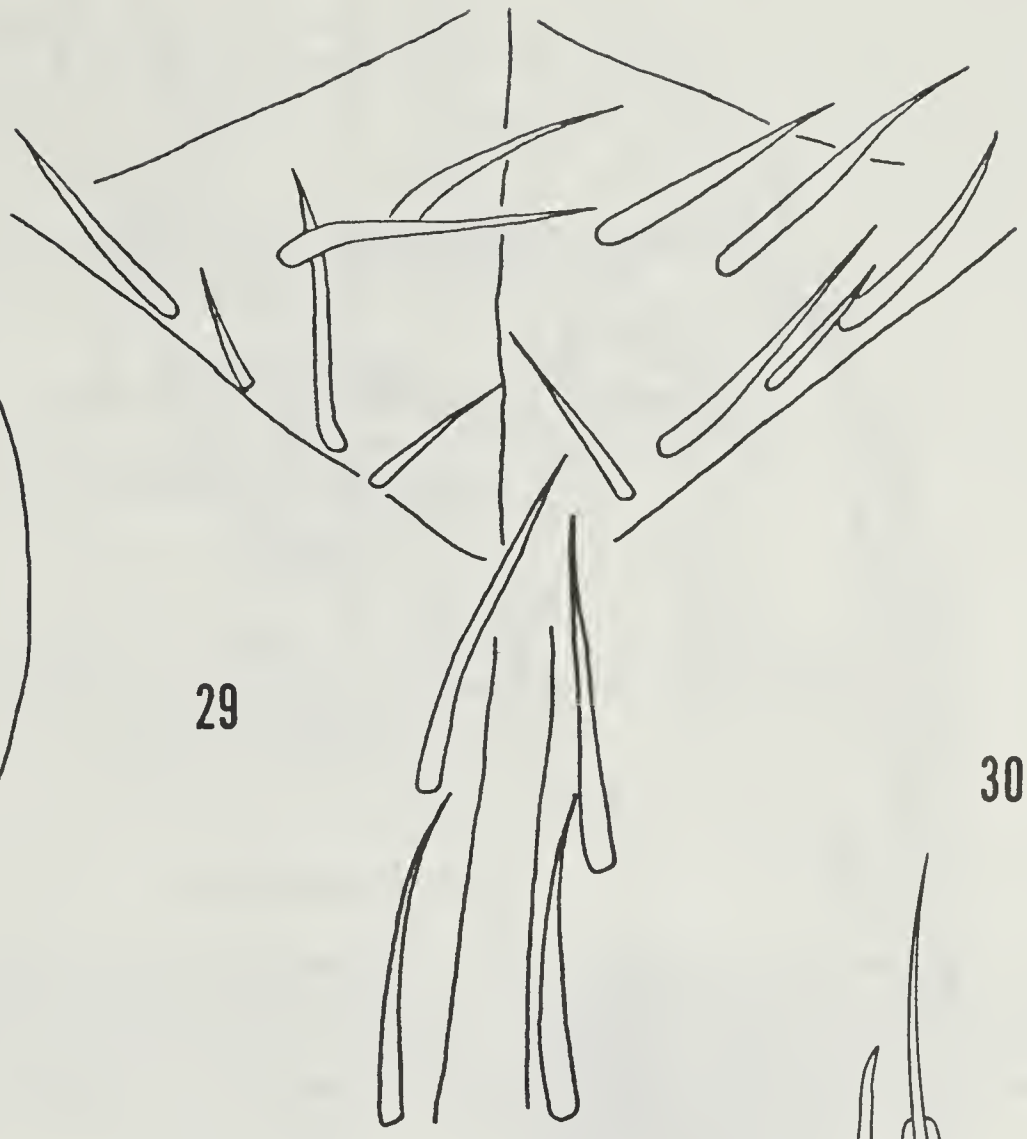

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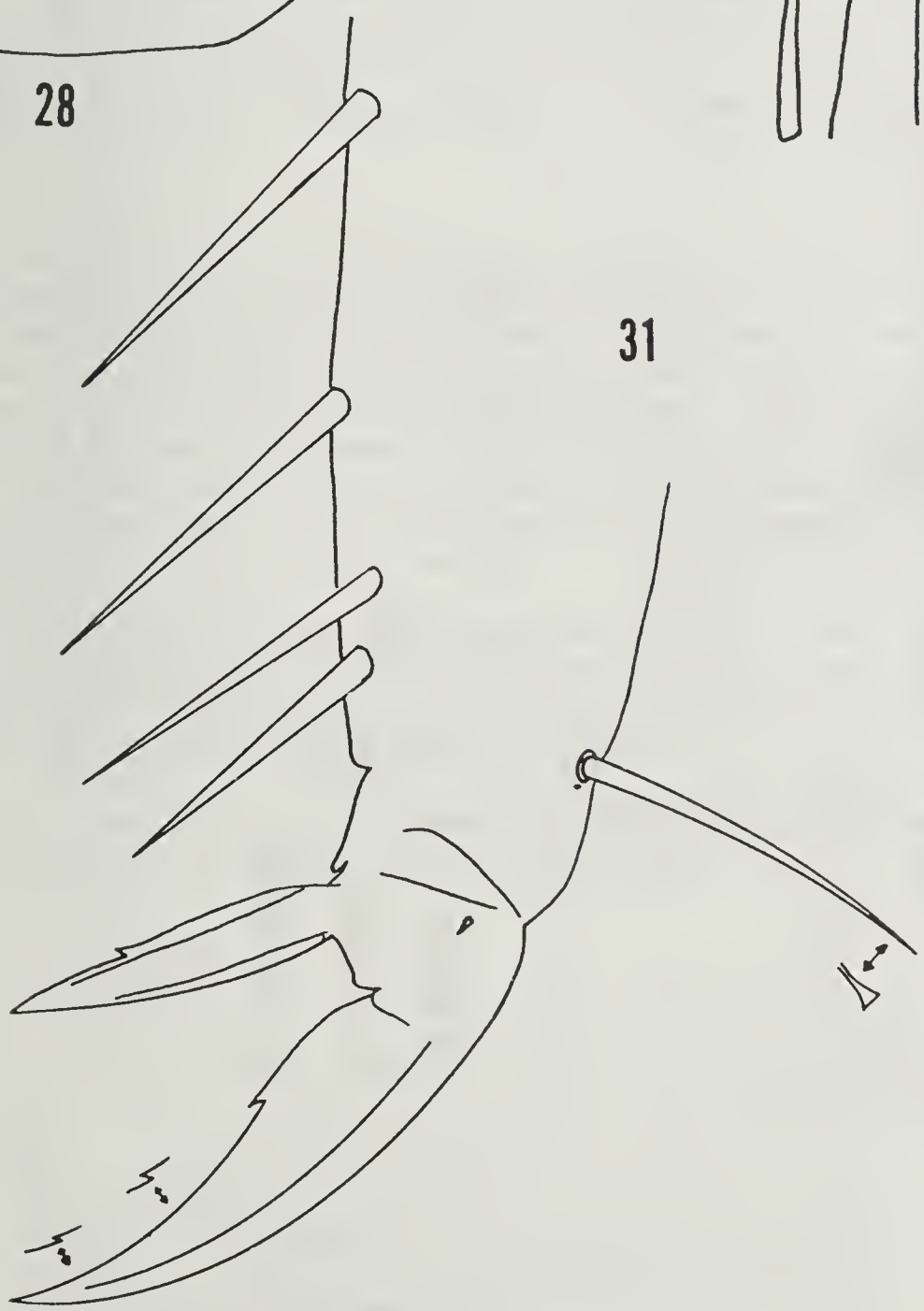

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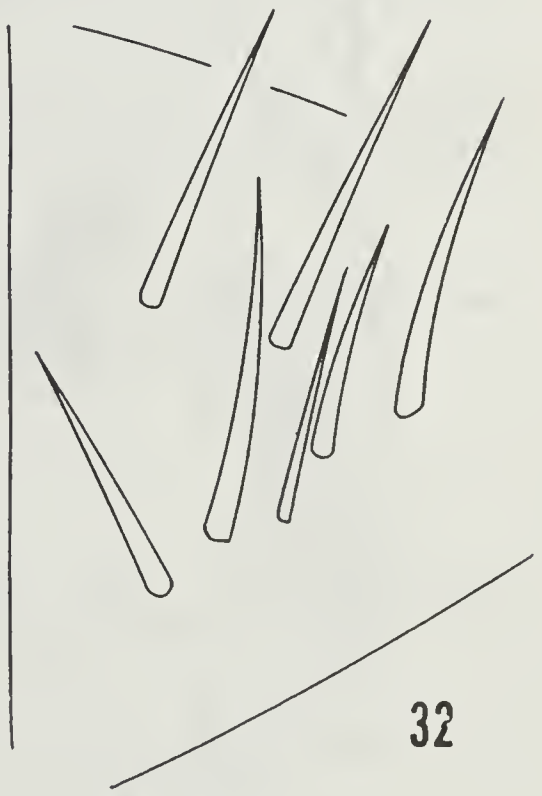

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Department of Geography
University of Illinois

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nitidus
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Parasites of the Gizzard Shad, DOROSOMA CEPEDIANUM LeSuer, from Two Southern Illinois Lakes

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ABSTRACT

A total of 2849 gizzard shad, Dorosoma cepedianum, *from two southern Illinois lakes, Crab Orchard and Carlyle, were examined for parasites. Nine different genera were recovered of which* Myxobolus *is reported for the first time from this host and* Pseudanthocotyloides banghami, Clinostomum, Proteocephalus, *and* Argulus *are reported for the first time from the gizzard shad of Illinois.*

During surveys of 1312 gizzard shad, *Dorosoma cepedianum,* from Crab Orchard Lake, Williamson County, Illinois, for *Gracilisentis gracilisentis* and 1537 gizzard shad from Carlyle Lake, Clinton County, Illinois, for *Plistophora cepedianae* records were kept on the occurrence of other species of parasites. Nine different genera were found of which *Myxobolus* is reported for the first time from this host and *Pseudanthocotyloides banhami, Clinostomum, Proteocephalus,* and *Argulus* are reported for the first time from the gizzard shad of Illinois (Table 1).

Myxobolus cysts 2 to 3 mm in size were found in the small intestine of 2 fish from Carlyle Lake. Spore shape and size were similar to that of *M. okobojiensis* Otto and Jahn, 1943, but both fish had been in 10% formalin for several months before examination making specific identification impossible at this time.

The following specimens have been entered in the USNM Helminthological Collection: *Gracilisentis gracilisentis* (74697): *Tanaorhampus longirostris* (74698): *Pseudanthocotyloides banghami* (74699): *Clinostomum* sp. (75295): *Proteocephalus* sp. (75294): *Bothriocephalus cuspidatus* (73743): and *Argulus* sp. (75296).

Table 1. Parasites of gizzard shad, *Dorosoma cepedianum,* from Crab Orchard Lake, Williamson County, and Carlyle Lake, Clinton County, Illinois.

Parasites	Crab Orchard Lake (1312 specimens)	Carlyle Lake (1537 specimens)
Protozoa		
Myxobolus sp.	—	2
Plistophora cepedianae	6+	654
Trematoda		
Pseudanthocotyloides banghami	22	—
**Clinostomum* sp.	7	—

Cestoda		
**Proteocephalus* sp.	2	3
Bothriocephalus cuspidatus	1	2
Acanthocephala		
Gracilisentis gracilisentis	733	—
Tanaorhampus longirostris	117	15
Crustacea		
Argulus sp.	7	—

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*Larval stages
+During the survey *Plistophora cepedianae* was not found in Crab Orchard Lake. However, 6 of 9 fish were found infected in March of 1979.

A Checklist of Parasites from the Gizzard Shad, DOROSOMA CEPEDIANUM LeSueur

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ABSTRACT

A checklist of parasites from the gizzard shad, Dorosoma cepedianum *is presented. The list consists of 3 species of Protozoa, 11 of Trematoda, 4 of Cestoda, 3 of Acanthocephala, 4 of Nematoda and 5 of Crustacea.*

Miller (1960) noted the gizzard shad is generally free from parasites. However, as work on this important forage fish has accumulated the list of parasites has become extensive. Several reports (Allison and Kelly, 1963; Putz *et al.,* 1965; Jilek, 1978; Price, 1979) also indicate that large populations of gizzard shad are susceptible to epizootics. The checklist presented below is believed to be complete. Numerals in parentheses signify the correspondingly numbered reference. An asterisk indicates the report is of a larval stage.

Checklist of Gizzard Shad Parasites

Protozoa

Ichthyophthirius multifliis Fouquet, 1876 — Coosa River, Ala. (1): *Myxobolus* sp. — Carlyle Lake, Ill. (21): Myxosporidia sp. — Lake Erie (4): *Plistophora cepedianum* Putz *et al.,* 1965 — Buckeye Lake, Ohio (3, 22): Carlyle Lake, Ill. (20): Crab Orchard Lake, Ill. (21).

Trematoda

Clinostomum sp. — Crab Orchard Lake, Ill. (21*): La. (2*): Cryptogonimidae — La. (2): *Diplostomulum* sp. — Lake Erie (4, 8*): *Gyrodactylus dorosomae* Rogers, 1975 — Logan Martin Reservoir, Ala. (23): *Mazocraeoides olentangiensis* Sroufe, 1958 — Olentangy River, Ohio, Norris and Reelfoot Lakes, Tenn., Tennessee River at Guntersville, Ala. (19): Lake Texoma, Okla. (9): *Mazocraeoides tennesseensis* Price, 1961 — Reelfoot Lake, Tenn. (19): *Mazocraes cepedianum* Kimpel, 1938 — Decatur Lake, Ill. (16); *Octobothrium* sp. — Reelfoot Lake, Tenn. (6); Lake Erie (4); *Posthodiplostomum minimum* MacCallum, 1921 — La. (2*); *Pseudanthocotyloides banghami* Price, 1959 — Reelfoot and Norris Lake, Tenn., Guntersville Lake, Ala. (19); Crab Orchard Lake, Ill. (21); *Pseudomazocraeoides megalocotyle* Price, 1959 — Reelfoot Lake, Tenn. (19); *Pseudomazocraeoides ontariensis* Hanek and Fernando, 1971 — Bay of Quinte, Ontario (7).

Cestoda

Bothriocephalus sp. — Reelfoot Lake, Tenn. (6*): *Bothriocephalus cuspidatus* Cooper, 1917 — Carlyle Lake and Crab Orchard Lake, Ill. (13): *Glaridacrus confusus* Hunter, 1929 — Tallahatchie River, Miss. (10): Lake Charleston, Ill. (15): *Proteocephalus* sp. — Lake Texoma, Okla. (9*): Carlyle Lake and Crab Orchard Lake, Ill. (21*): La. (2*).

Acanthocephala

Gracilisentis sp. — Elephant Butte Lake, N. Mex. (11): *Gracilisentis gracilisentis* Van Cleave, 1913 — Illinois River, Ill. (28): Crab Orchard Lake, Ill. (12): Lake Texoma, Okla. (9): Tallahatchie River, Miss. (29): La. (2): *Tanaorhampus longirostris* Van Cleave, 1913 — Illinois River, Ill. (28): Crab Orchard Lake, Ill. (12): Carlyle Lake (21): Lake Texoma, Okla. (9): Reelfoot Lake, Tenn. (6): Tallahatchie River, Miss. (29): La. (2).

Nematoda

Unidentified larvae — Lake Erie (4*): Ascaroidea — Lake Carl Blackwell, Okla. (24*): *Agamonema* sp. — Reelfoot Lake, Tenn. (6*): Lake Erie (5*) *Camallanus oxycephalus* Ward and Magath, 1916 — Lake Charleston, Ill. (15): Lake Erie (26, 27*).

Crustacea

Argulus sp. — Elephant Butte Lake, N. Mex. (11): Crab Orchard Lake, Ill. (21): *Argulus alosae* Gould, 1841 — Woods Hole Region, Mass. (30): *Argulus appendiculosus* Wilson, 1907 — Little Star Lake, Wis. (17): *Ergasilus clupeidarum* Johnson and Rogers, 1972 — Uphapee Creek and Tallapoosa River, Ala. (14): *Ergasilus lanceolatus* Wilson, 1916 — Ky. (31).

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A NOTE ON THE DISTRIBUTION OF WILD LEEK IN ILLINOIS

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ABSTRACT

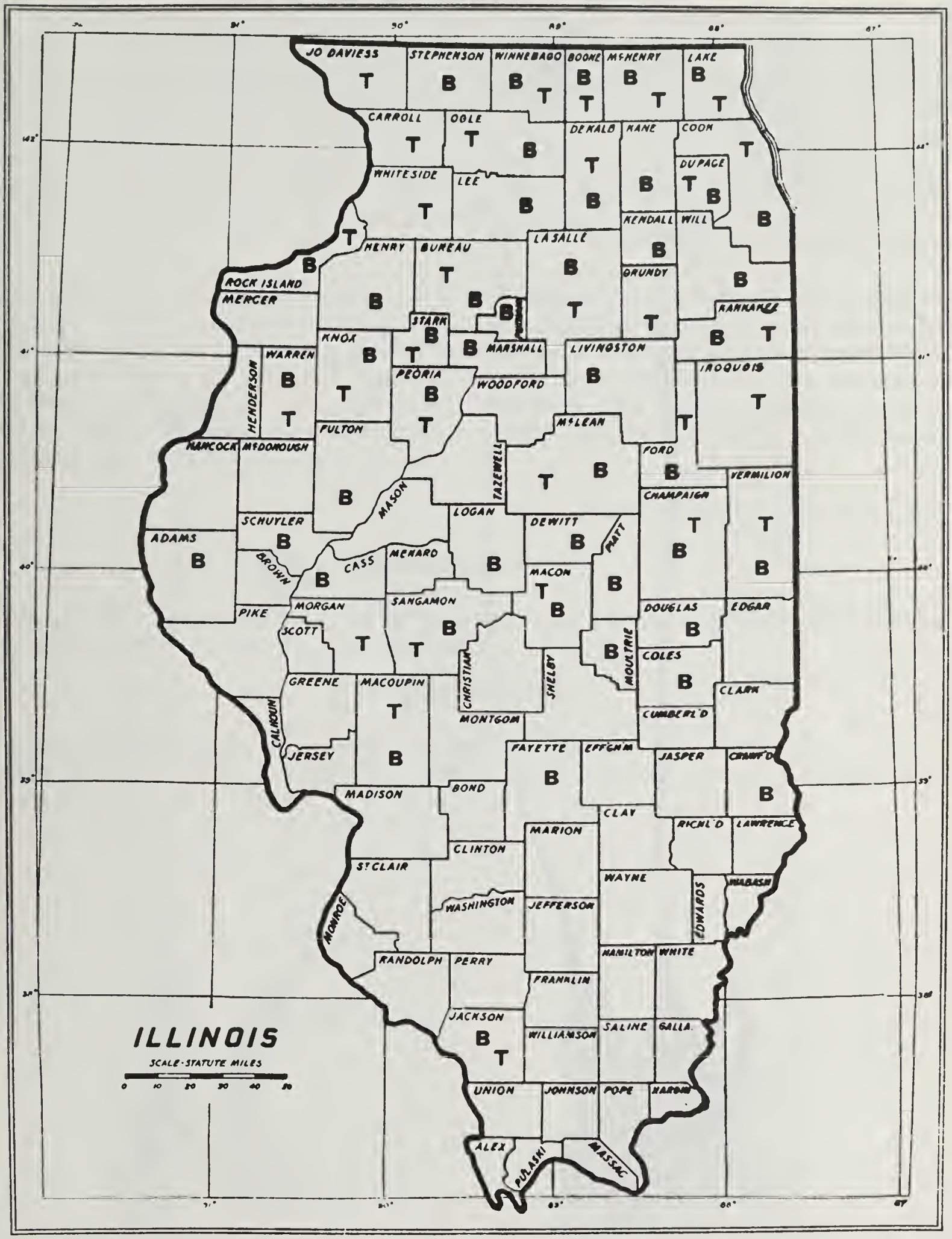
Two species of wild leek are recognized, Allium burdickii *(Hanes) A.G. Jones and* A. tricoccum *Sol. in Ait. County records indicate that their ranges in Illinois largely coincide. However, discontinuities are evident which may or may not be significant. The purpose of this note, which provides a distribution map and a key to the two species, is to stimulate further collecting in Illinois toward a completion of the report on distribution and frequency of occurrence of these plants.*

In a recent paper (Jones, 1979), evidence was presented indicating that the two morphological variants of wild leek formerly united under *Allium tricoccum* Solander in Aiton (Liliaceae) are reproductively isolated, and should be recognized as distinct species. The segregate taxon, previously reported at the rank of variety by Hanes (1953), is *A. burdickii* (Hanes) A.G. Jones. Collections studied were obtained from 45 herbaria, including the major Illinois institutions: EIU, F, ILL, ILLS, ISM, ISU, MOR and SIU. When the entire geographic range is considered, *A tricoccum* seems to be the more widely distributed and probably more common of the two species. Plants of *A. burdickii* are comparativley uncommon in the eastern United States and southeastern Canada, and of rare or doubtful occurrence in the Ozarkian region of southern Illinois and adjacent Missouri. In the midwestern Great Lakes region, however, the picture seems reversed, *A. burdickii* being the more common of the two species.

For a ready comparison and assessment of the situation in this state, Illinois county records confirmed by us (the species identified by the first letters of their respective epithets) have been plotted on a single map (Fig. 1). Specimens of *A. tricoccum* were available from 30 and of *A. burdickii* from 45 counties. The apparent sharp difference between our map and the distribution recorded by Mohlenbrock & Ladd (1978) is attributable to an error. Legends for the two taxa, recognized in their book at varietal rank, were inadvertently exchanged. We did not locate collection vouchers from Hancock, Massac, Pope and Scott counties listed by the above authors and, being unsure about the identity of the plants from those stations, we have not included the records on our map. As it stands, there is good reason to assume that the distribution record is incomplete and that the apparent discontinuities, e.g. the one between Jackson County and Macoupin, Fayette and Crawford counties, are artifactual.

Plants of wild leek are most prominent in the early spring when they are not in flower, and since the succulent leaves and fleshy bulbs require a specil effort in the preparation of attractive herbarium specimens, they may have been slighted by the casual plant collector. Many herbaria have comparatively few sheets of wild leek in their collections. In addition, plants of *A. burdickii* are smaller and can be fitted more readily on a herbarium sheet than those of *A. tricoccum.* Not knowing their distinctness, some collectors may have chosen plants of the former in preference to those of the latter in places where the two taxa are sympatric.

Many aspects of the natural history of these closely related and partly sympatric species of *Allium* remain obscure at this time because of deficiency in field observations. Label data rarely give precise habitat information or document frequency of occurrence in any one locality. The purpose of this note is to stimulate further collecting of wild leek, and the gathering of concise field data under utilization of the recently published new information. In the earlier (1979) paper, morphological and phenological characteristics of the two species were given in the form of tabulated comparisons. For this report, the diagnostic features are presented as a key.



1. Illinois county records of wild leek: B = *Allium burdickii* (Hanes) A.G. Jones; T = *A. tricoccum* Solander in Aiton.

2. Wild leek collected in Funks Grove, McLean County, IL, on July 10, 1977: *Allium tricoccum* on the left, *A. burdickii* on the right.

KEY TO THE SPECIES OF WILD LEEK (Fig. 2)

Plants forming extensive clonal colonies; bulbs ovoid, 4-6 cm long and 1.5-3 cm in diameter; leaves elliptic to oblong-oblanceolate, tapering into a distinct petiole-like base, (15-)20-30(-40) cm long and (3-)5-8(-9) cm wide, the sheaths, petioles and lower portion of midribs maroon red; scapes rising (12-)25-35 cm above the ground when fully grown, flexuous and bent in the upper portion; inflorescence buds usually nodding, the scapes and bracts at least somewhat red pigmented; umbels comprised of (20-)30-50(-60) flowers; perianths and capsules 4-6 mm high; seeds 3.0-3.2 mm in diameter. Flowering period: throughout July (occasionally into August).

1. *Allium tricoccum* Solander in Aiton

Plants growing in small scattered clusters of 3-20 individuals; bulbs slenderly ovoid, 2-4(-5) cm long and 1-1.5(-2) cm in diameter; leaves linear to linear-lanceolate, lacking a distinct petiole-like base, (10-)14-24(-28) cm long and (1.5-)2-4(-4.5) cm wide, the sheaths and leaf-bases white; scapes green, lacking any trace of red pigment, rising (10-)13-16(-18) cm above the ground when fully grown, usually straight, the green-bracted inflorescence buds upright; umbels comprised of (-6)12-18(-24) flowers; perianths and capsules 3-5 mm high; seeds 2.8-3.0 mm in diameter. Flowering period: throughout June.

2. *Allium burdickii* (Hanes) A.G. Jones

ACKNOWLEDGMENTS

We gratefully acknowledge the loan of specimens from the following herbaria (identified by their acronyms): EIU, F, ILLS, ISM, ISU, MOR, SIU.

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NATIVE ILLINOIS *DELPHINIUM*

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ABSTRACT

Native Delphinium *species of Illinois were studied to clarify the status of these species in the state.* Delphinium tricorne *Michaux,* D. carolinianum *Walter and* D. virescens *Nuttall had previously been reported in Illinois. Taxonomic problems involving* D. carolinianum *and* D. virescens *were solved using systematic techniques including flavonoid chemistry, seed protein analysis and morphological examination. These data suggested that the* Delphinium *plants occurring naturally in Illinois belong to two taxa:* D. tricorne *and* D. carolinanum. Delphinium tricorne *was found to be the most common* Delphinium *in the state. The species was widespread south of a line through Henry and Vermilion counties and less common northward.* Delphinium carolinianum *was restricted to hill prairies and prairie remnants. Chemically and morphologically,* D. tricorne *and* D. carolinanum *are quite distinct from one another. It was determined that plants identified as* D. virescens *from Illinois were actually white flowered specimens of* D. carolinianum.

INTRODUCTION

Three species of *Delphinium* (Ranunculaceae) are presently listed as native to Illinois. *Delphinium tricorne* Michaux is a common late spring blooming wildflower in much of Illinois. *Delphinium carolinianum* Walter is much less common and found locally on hill prairies and prairie remnants. Another larkspur, *D. virescens* Nuttall is included in the Illinois flora by Jones (1971) and Mohlenbrock (1975). Previous references to *D. virescens* in Illinois are based on an 1847 collection by S.B. Meade, made near Augusta in Hancock County. Meade referred the specimen to *D. azureum* Michaux, a synonym for *D. carolinianum* and Kibbe (1952) included the plant in *D. carolinianum.* A survey of the literature indicates extensive confusion as to the taxonomic status of *D. carolinianum* and *D. virescens* (Ewan, 1945: Keener, 1976).

MATERIALS AND METHODS

Herbarium sheets of the *D. carolinianum—D. virescens* complex from twenty-two nationwide herbaria were examined. Specimens of *D. tricorne* from herbaria at ILL, ILLS, MO and MWI were examined. Extensive field sampling and observations were made of *Delphinium* in Illinois. Taxonomic problems in the *D. carolinianum* complex were solved using several systematic techniques (Warnock, 1979). Flavonoids were examined using the separation and identification techniques outlined in Mabry *et al.* (1970). Seed proteins were separated electrophoretically on polyacrylamide gels using techniques developed by Ornstein (1964). Protein banding patterns were assessed using the similarity index of Crawford (1974). Morphological measurements of twenty-four characters were made on live plants as well as herbarium specimens.

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RESULTS

Although 24 morphological characters were examined, not all of these were important in distinguishing the taxa. Root type, pedicel length and orientation, seed coat and shape, fruit shape and leaf structure were used to separate *D. tricorne* from the *D. caorlinianum—D. virescens* complex. Within the complex, sepal color, spur length and structure and placement of leaves were the most important morphological characters for recognizing the taxa. Compared with specimens from other parts of the range of *D. carolinianum—D. virescens,* plants of the complex in Illinois were all very similar to one another morphologically. The major source of morphological variation in Illinois populations of *D. carolinianum* was in sepal color.

Flavonoid analysis of the floral pigments of *D. carolinianum* showed that white and blue flowers of this group contain identical compounds but in differing proportions. Thus, the anthocyanin (a delphinin derivative) is in relatively greater concentrations in the bluer flowers and the flavonol copigment (a 3-0-glycoside of quercetin) is relatively more common in the whiter flowers. Flower color is apparently environmentally controlled since the colors were altered when the plants bloomed following transplantation to a greenhouse.

Chromatographic patterns of leaf flavonoids from four populations (Fig. 1) of the *D. carolinianum—D. virescens* complex in Illinois were nearly identical. Comparatively more variation was found in patterns of flavonoids of plants from other parts of the range of the complex and the flavonoids of Illinois plants were most similar to those of subspecies *carolinianum*. *Delphinium tricorne* was easily distinguished using morphological characters. Therefore, neither flavonoids nor seed proteins were studied.

Figure 1. Two dimensional paper chromatograph of *Delphinium carolinianum*. All spots are purple, turning yellow with ammonia vapor under ultra violet light.

Analysis of seed protein patterns of *D. carolinianum* from Illinois showed average similarity of pattern of 69.2% between populations. Average similarities between individuals within single populations were 78.9%. Over the entire range of the complex, interpopulational protein banding pattern similarities averaged 63.6%. Morphological, flavonoid and seed protein data suggested the inclusion of all Illinois specimens of the *D. carolinianum—D. virescens* complex in *D. c.* subspecies *carolinianum*.

DISCUSSION

Delphinium tricorne is commonly referred to as the dwarf larkspur since it is the smallest larkspur (30-60 cm tall) native to eastern North America. This species grows in the woodlands and wood edges throughout most of Illinois south of a line through Henry and Vermilion Counties (Mohlenbrock and Ladd, 1978). Scattered recent collections of *D. tricorne* north of this line indicate that the species may be widespread in the northern counties which are less extensively collected than the rest of the state. *Delphinium tricorne* is found in eastern Iowa and southern Wisconsin. Therefore, new county records for *D. tricorne* in northern Illinois will not be surprising.

Plants of *D. tricorne* are usually rooted in fairly moist soil, often at the base of a bluff or on a hillside. Flowering begins in mid April in southern Illinois and may extend through May in north-central Illinois. Flowers are usually deep violet or blue-purple but may be lighter colored and rarely white. Flowers are borne on 2-5 cm long pedicels which diverge from the axis of the inflorescence at their origin. The inflorescence is a narrowly pyramidal raceme, usually without branches. Leaves are nearly all cauline and basically tripartite with the three main divisions more or less dissected near their apices. Follicles are normally three per flower and curved outwards at maturity, thus strongly apically divergent. Seeds are dark brown to black, somewhat oval and with a smooth, often shiny coat.

Delphinium carolinianum is generally a larger plant (70-120 cm tall) than *D. tricorne*. Plants of *D. carolinianum* are fairly common locally on the hill prairies on the bluffs of the Mississippi River from Pike to Henderson Counties. The plants are also common on the sand prairie areas of Henderson and Mercer Counties. A single locality in a prairie remnant near Dalton City on the Macon-Moultrie County line, indicates that *D. carolinianum* may once have been more widespread in the prairies of Illinois. The population near Dalton City may have been exterminated by the recent construction of a new highway in the area. An old collection of *D. carolinianum* from St. Clair County suggests that the species was once more widespread on the Mississippi bluffs in Illinois. *Delphinium carolinianum* is also found on the bluffs on the Missouri side of the river. Future collections from the sand prairies of Mason County and the Thomson and Savanna Army Depot sand prairies in Carroll and Jo Daviess Counties may include *D. carolinanum*. The species may also be discovered on the hill prairies of Mason County as well as bluffs in Carroll and Jo Daviess Counties.

Flowers of *D. carolinianum* are white to light blue in Illinois. Anthesis occurs from late May to mid June. Flowers are borne on 1.0-2.5 cm long pedicels. Pedicels are parallel to the axis of the inflorescence for most of their length, diverging only for the last 2-4 mm. The inflorescence is a strict virgate raceme without branches. Leaves at anthesis are all cauline, the basal leaves usually withering before the flowers open. Leaves are highly dissected, the three major divisions often indistinct. Ultimate leaf segments are normally less than 2 mm wide. Follicles are normally three per flower (4-6) and more or less erect at maturity. Seeds are wedge or crescent shaped and dark brown with seed coats of vesicled scales.

SUMMARY

Examination of *Delphinium* in Illinois by observing natural populations and study of herbarium specimens indicates the presence of two native species in the state. These are *D. tricorne* and *D. carolinianum*. *Delphinium virescens* is not found in the state although it had previously been reported. The specimen attributed to *D. virescens* is actually a white flowered form of *D. carolinianum* subspecies *carolinianum*.

ACKNOWLEDGMENT

Loans of specimens from the following herbaria are gratefully acknowledged: ARIZ, CAS, CS, COLO, DUKE, GH, ISC, KANU, MO, ND, NMC, NY, OSC, PH, POM, RM, RSA, TENN, TEX, UC, UMO, and USFS. Permission of the curators of the following herbaria to examine specimens is also appreciated: ILL, ILLS, ISM and MWI. Abbreviations of herbarium names are those found in *Index Herbariorum* (1974).

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Microcomputer Controlled Hydraulic Circuits

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ABSTRACT

Linear actuators in the hydraulic circuits can either be mechanical or Solenoid controlled direction valves. Random and computer logics are the two alternatives for electronic actuators. The actuators with computer logic can perform various sequences with programmed controls and can be very effective in terms of cost, speed, and reliability.

INTRODUCTION

Many hydraulic circuits encountered in industry require a series of linear actuators. Circuits commonly used today employ sequencing valves, mechanically operated direction valves, or solid state logic circuits. The solid state logic circuits may either be of random or of computer logic type. The random logic circuits are designed for specific (fixed) sequence requiring considerable hardware change for changing the actuator sequence. The computerized logic circuits are software controlled and therefore, the actuator sequence can be changed without any change in the hardware. With the advent of the microprocessor, many options are available for sequencing linear actuators with computerized logic circuits. Microcomputers can be used in programmed, interrupt, or Direct Memory Access I/O mode. The programmed I/O is both software initiated and software controlled, whereas the interrupt I/O is hardware initiated and software controlled.

This paper illustrates how the microcomputer can be used in a particular multi cylinder-sequencing problem in the interrupt mode. The problem chosen for illustration is that of a situation with seven different sequences. Each sequence in the cycle involves four cylinders A,B,C, and D. The arbitrarily chosen order for one of the sequences in the cycle is A+, C+, C-, B+, D+, B-, D-, A-. The first sequence in the sequence transition has the top priority. Initially, the sequence status flags for all the sequences are on. Upon power up, the microcomputer starts with the first sequence and proceeds with the priority rule established by the sequence transition within the cycle. Once all the sequences are completed, the cycle is repeated indefinitely.

THE CIRCUIT

A microcomputer controlled hydraulic circuit is shown in figure 1. On the hydraulic side, there are seven 4-cylinder sequences. The cylinders in each group are connected to 2- position 4-way, solenoid actuated, spring return directional valves. Limit switches at the actuator extremities supply electrical signals indicative of the status of each actuator. A typical sequence arrangement is shown in figure 2.

The electrical side of the circuit is shown in figures 3, 4, 5 and 6. A 8080-based microcomputer system provides the actuating signal for the solenoid. The system consists of input, output, interrupt, and processor circuits along with the appropriate software stored in memory. There are seven input ports, one for each sequence, to sense the limit switches. Each sequence consists of four cylinders and therefore, eight limit switches must be provided to monitor the cylinder position. The microcomputer system is a computer logic circuit with a common data bus for all the peripherels in the system. Since there can be no more than one active source on the bus during data transfer operations, these limit switches should be connected to the bus through a 8-bit buffer, 8212. These buffers must be controlled with device select pulses from the control bus.

The solenoids are actuated by the output ports. There are seven 4-bit latch type output ports. These latches are interfaced with the microcomputer system through the data, control, and the address buses. The output port interface for a typical sequence is as shown in figure 4. Since there are more than one input and output ports, the device select pulses for the I/O ports must be generated by a decoder using the control and the address buses as shown in figure 5.

The microcomputer system is built around an 8080 microprocessor. The cpu has a 16-bit address bus and an 8-bit data bus. This permits the processor to handle up to 65k bytes of memory, 256 inputs ports, and 256 output ports. The most important characteristics of the processor is its interrupt capability. The cpu can be used in programmed, interrupt, or in the Direct Memory Access mode. The mode selection can be selected on the 'Fly' and to make the decision for selecting the mode, one has to be aware of the fact that the programmed I/O puts the cpu in a timing loop thereby reducing the data transfer rate. In the case of interrupt I/O, the cpu is switched between different programs by a hardware signal. This enables the system to have a higher data transfer rate. This feature in the interrupt I/O mode demands an extensive switching circuits. Therefore, the mode-decision is to make a trade-off between hardware switching circuit cost and the data transfer rate.

The interrupt interface begins with seven sequence status flags representing the status of the sequences. These flags are implemented with seven flip flops. The logic^{-1} content of a flip flop indicates that the appropriate sequence needs a complete sequencing or the current sequence is incomplete. Whereas, a logic-O indicates that the appropriate sequence is complete and the cpu is currently processing the down-stream sequences in the cycle. At the beginning of the cycle, the processor sets all the flags at logic 1. Every time a sequence is completed, the appropriate flag is reset.

The status flags are interrupt request devices requesting the processor for sequencing service. The sequence transition diagram for the example problem is as shown in Fig. 8. The sequences in the cycle are of different types. For example, they may represent operations such as drilling, and milling with different machine tools. Therefore, the cpu is confronted with the problem of device identification. This can be alleviated either by a polled approach or by a hardware circuit. In this example, a priority encoder circuit is used to implement the sequence transition as in Figure 8. The encoder generated a 3 bit output and an interrupt request signal according to the inputs from the status flags. The 3-bit binary number represents a RST instruction and is interfaced with the system through an 8212 tri-state buffer using the data and control buses. The interrupt request output of the encoder is connected to the INT line of the processor.

CIRCUIT OPERATION

The software for the circuit operation must include eight service routines or traps. The first routine is called the power-up routine. When the system is powered up, the processor starts with the power up routine. The power up routine, figure 7, defines the stack memory, sets the sequence status flags, enables the interrupt, and waits for interrupt at the halt mode. Since all the status flags are set, the encoder generates the interrupt request signal and RST-1 output. The cpu generates INTA control signal to turn on the 8212 buffer in the interrupt circuit. When RST-1 instruction reaches the cpu, it switches the cpu into the trap #1. In the trap, the processor performs the sequencing, resets the appropriate status flag, returns back to the power up routine, and waits for interruption. Since the upstream status flag is disabled, the next output from the encoder will be RST-2. The cpu, now, will be switched into the trap #2. This logic will be repeated until the cycle is completed. During the last sequence in the cycle, the cpu will set all the flags before returning to the power up routine.

The flow chart, shown in figure 9, describes a typical trap logic. At the beginning of the trap, a memory pointer is set to address the location in memory where the first command word is stored. The processor reads the first command word in memory and loads the last four bits of it into the

output port. In the example sequence, the command word would be XXXX1000. This command word produces a positive drive voltage on solenoid A, and zero voltages on solenoids B,C, and D. This actuator A is commanded to extend, while B,C, and D remain retracted. The cpu then reads the input port to ascertain the status of the actuators. By comparing the feedback signals to the command word it can determine whether or not the most recent command word has not been carried out, so the processor waits until the difference goes to zero by looping backward. When the feedback word equals the command word, the cpu tests whether the end of the sequence has been reached by checking whether the memory pointer has been incremented eight times (the example sequence requires eight command words). If the pointer has been incremented eight times, the processor resets the flag and returns to the power up routine.

In the last sequence in the cycle, upon incrementing the pointer eight times, the cpu also sets all the flags for repeating the cycle. The list of command words for the example sequence is given in Table 1.

CONCLUSION

In the example problem an 8 bit processor was chosen. It can handle only 256 input and 256 output ports. If a complex cycle is to be controlled, one may have to explore the possibility of using processors that can handle more ports. The advantage of the computerized actuators is that they can perform various sequencing functions without hardware change. This feature may enable better utilization of hardware on a functional basis as compared with random circuits. The designer has to be alerted to the fact that the computer logic is not always the solution. The choice between random and computer logic should be based upon the number of sequences, speed, reliability, and cost.

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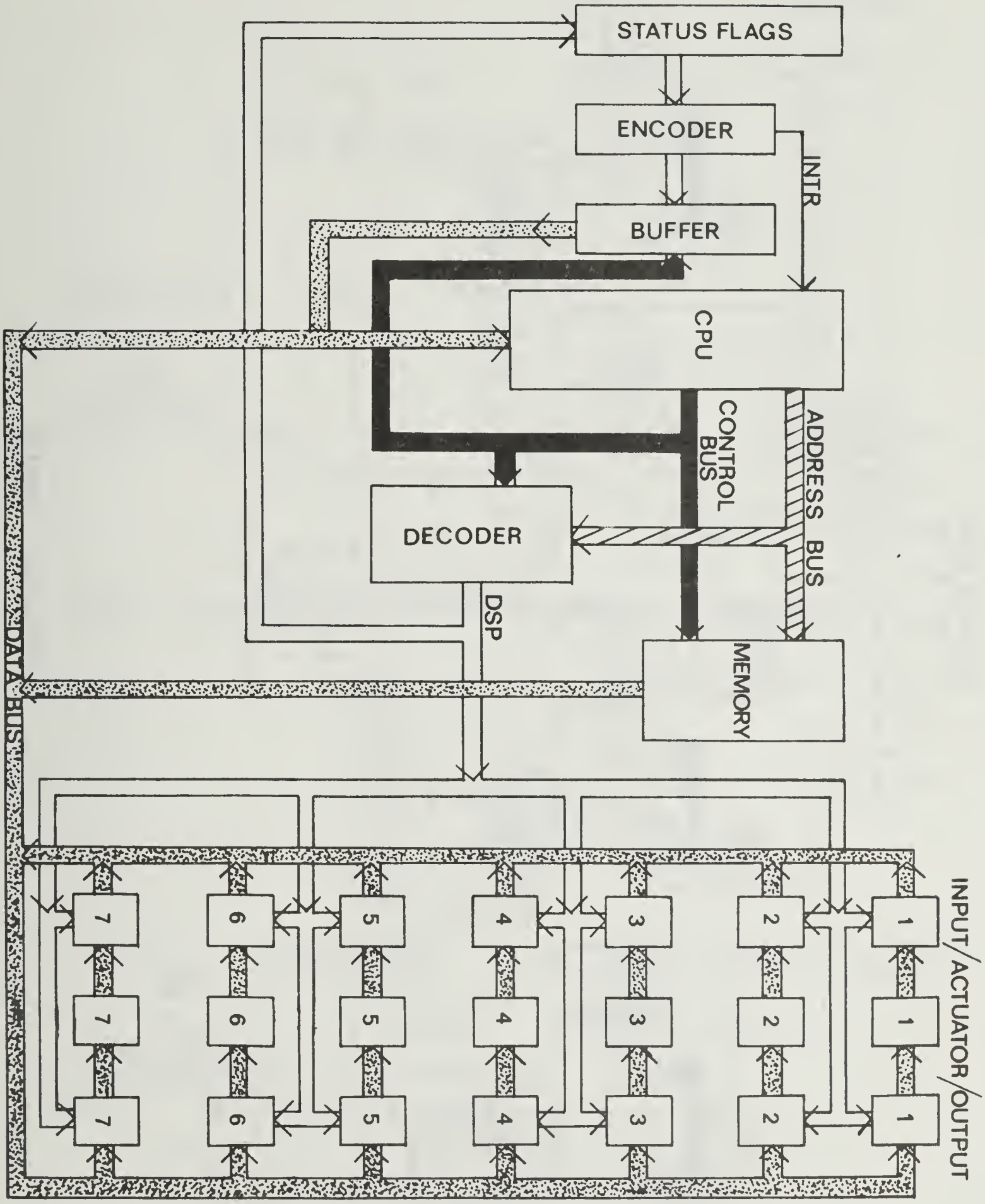

FIG. 1 MICRO CONTROLLED HYDRAULIC CIRCUIT

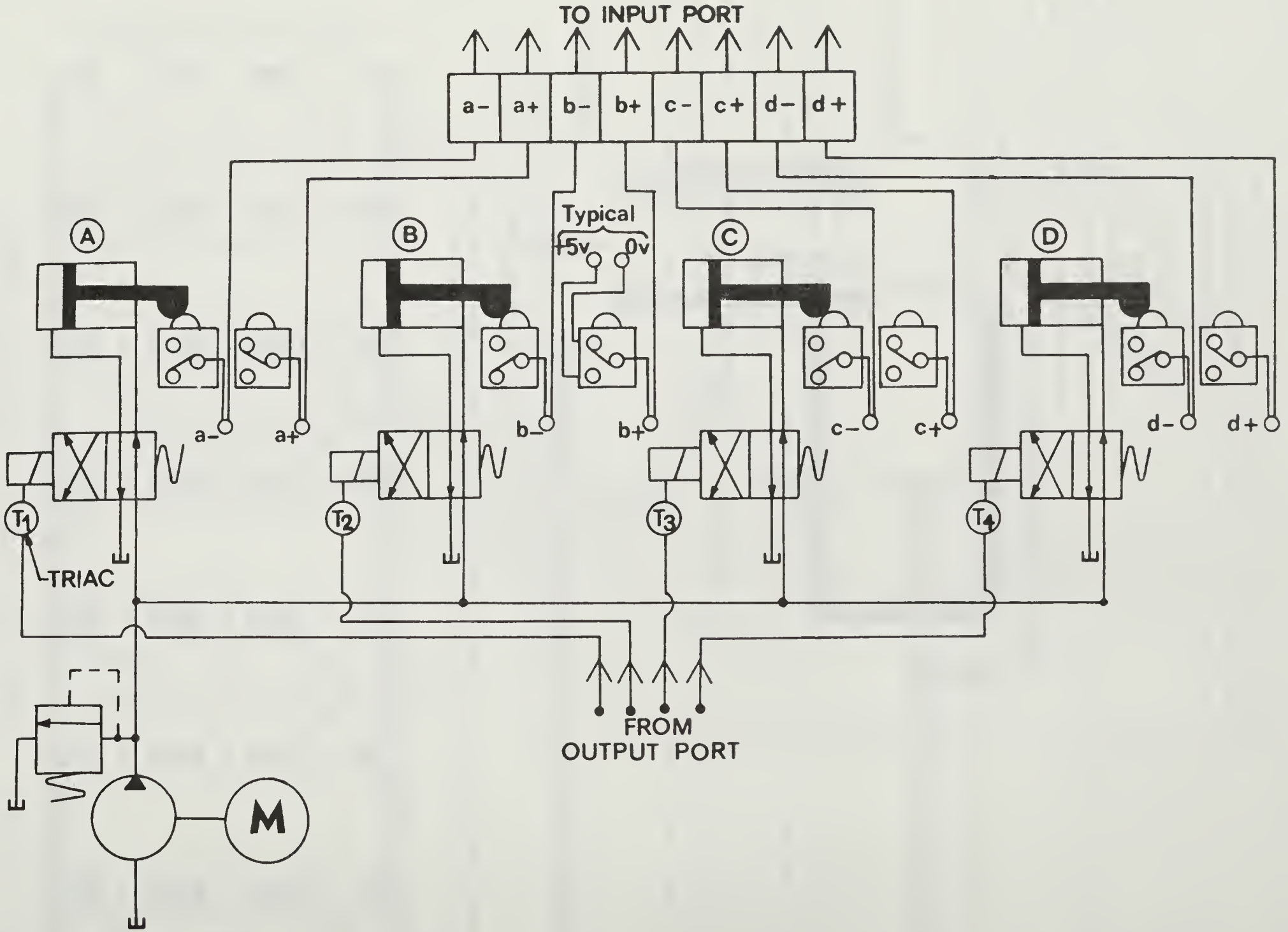

FIG. 2 HYDRAULIC CIRCUIT

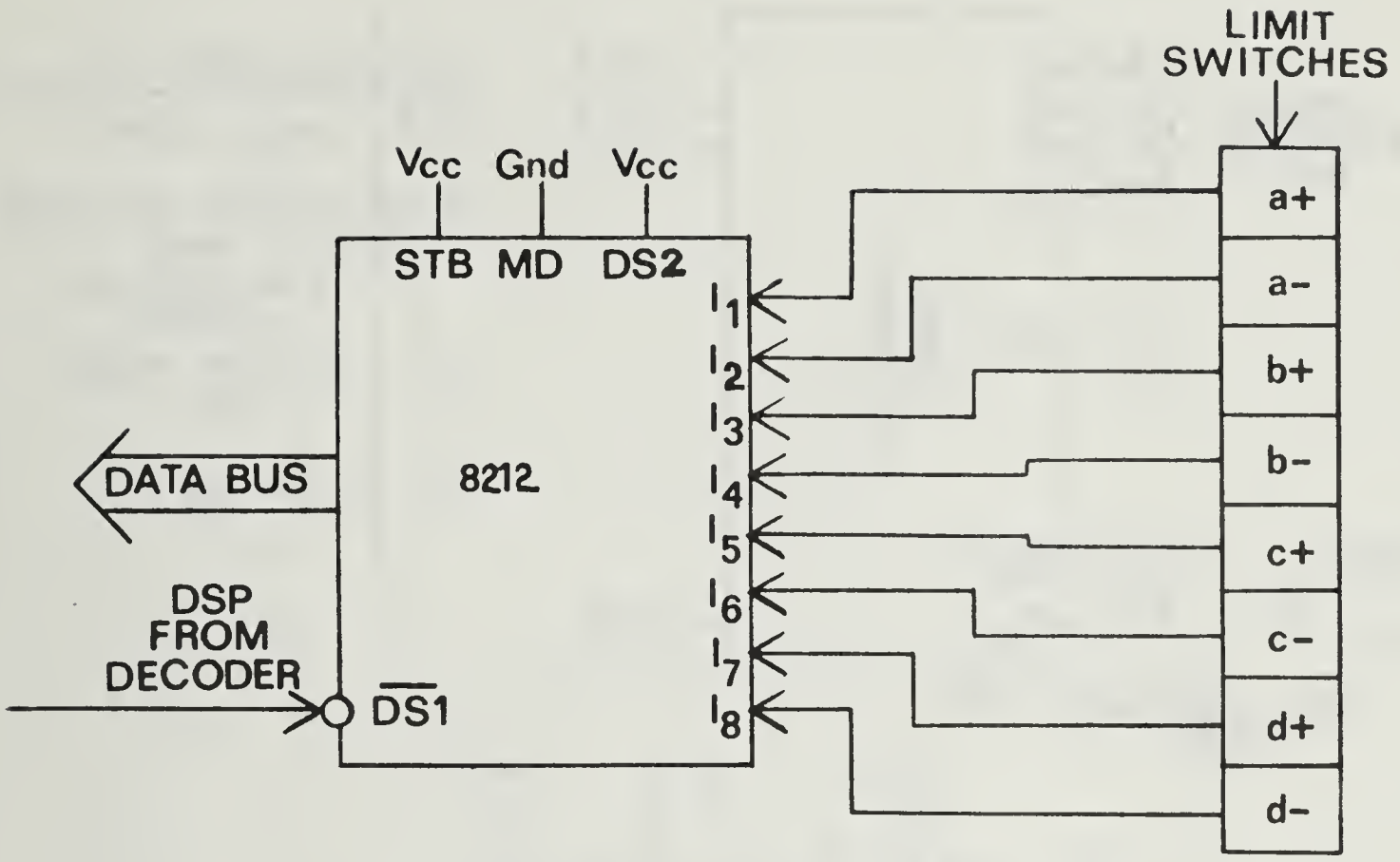

FIG. 3 INPUT INTERFACE FOR A TYPICAL SEQUENCE

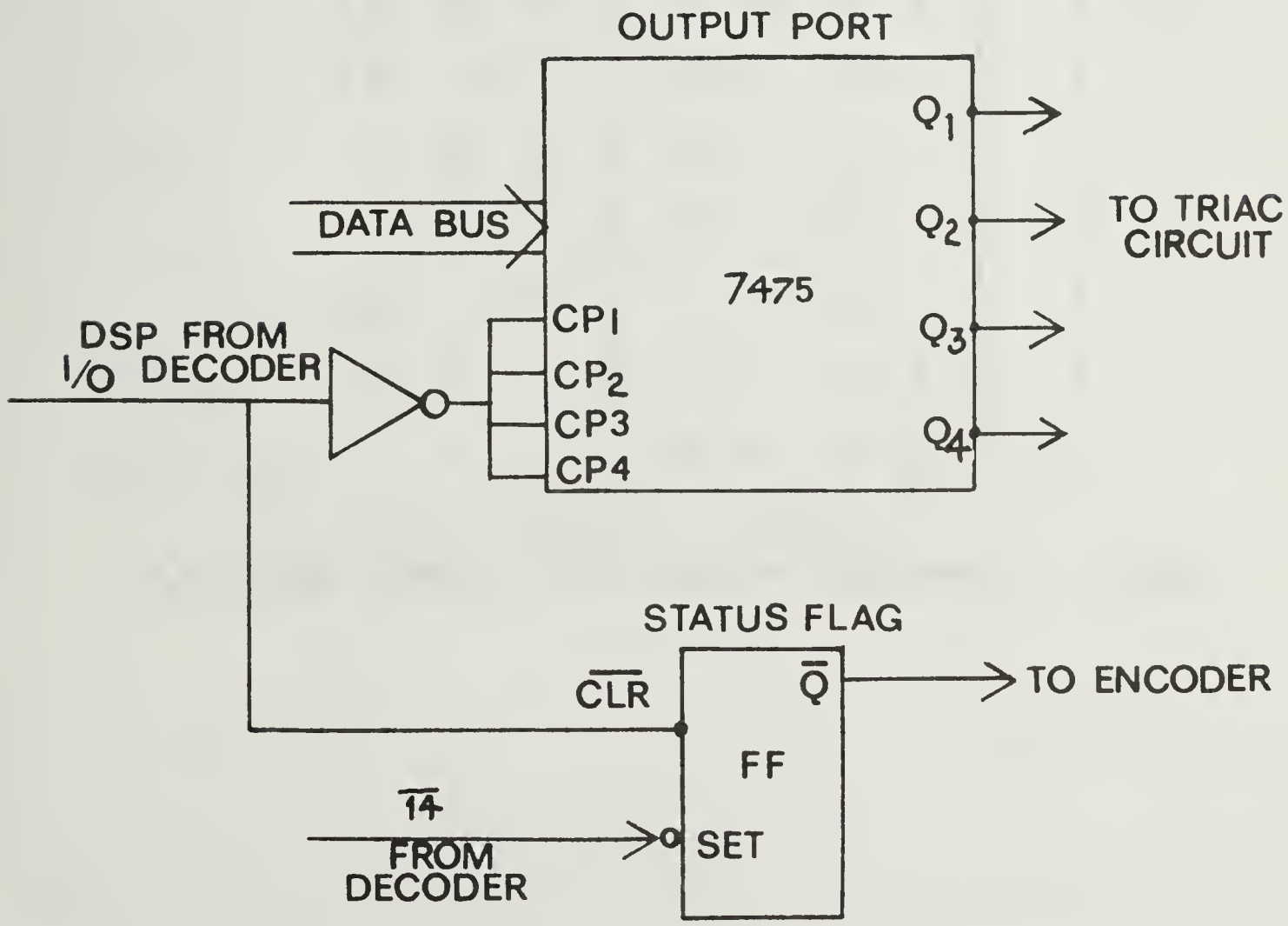

FIG. 4 OUTPUT INTERFACE FOR A TYPICAL SEQUENCE

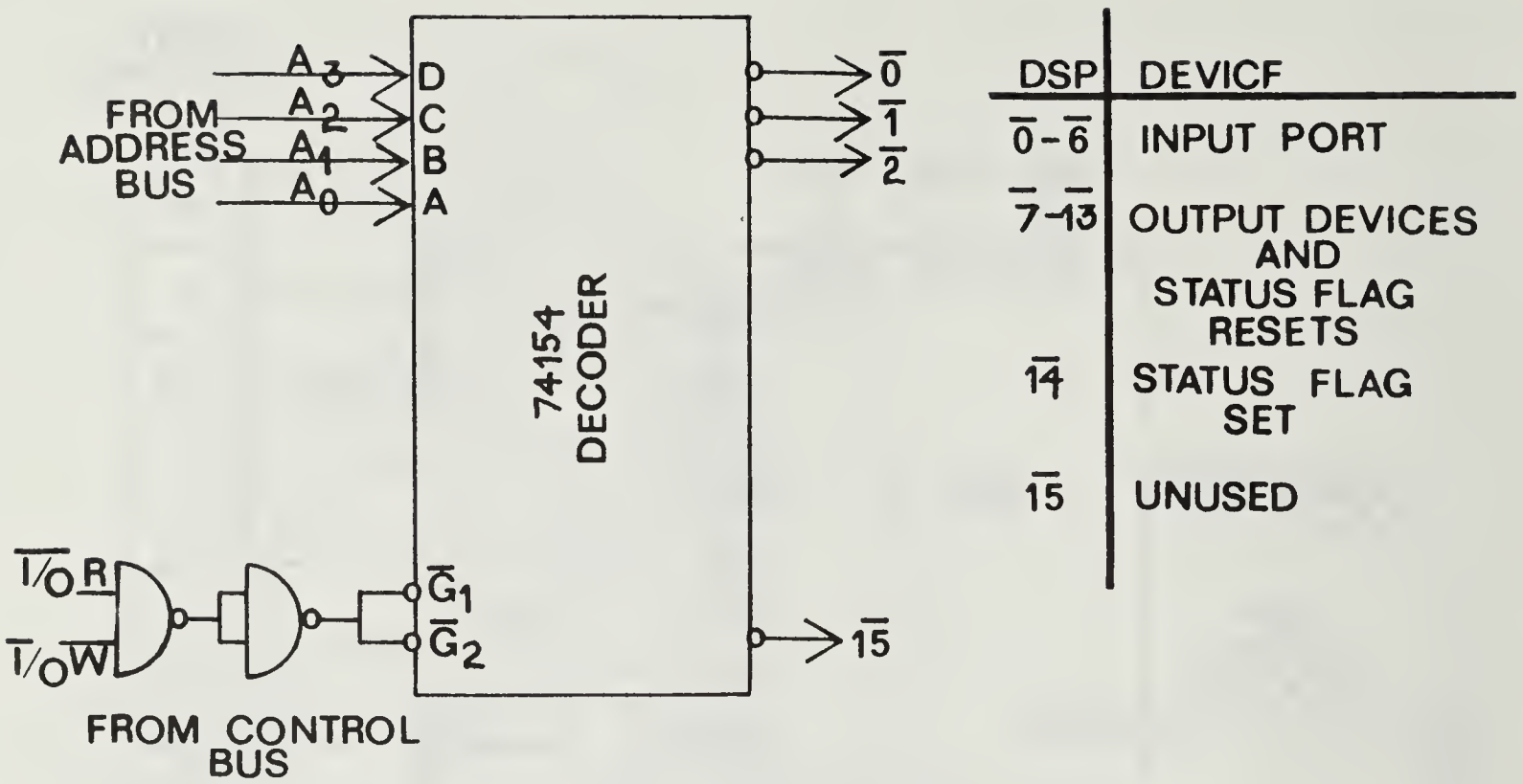

FIG. 5 I/O DECODER

COMMAND NO.	a+	a-	b+	b-	c+	c-	d+	d-
1	1	0	0	0	0	0	0	0
2	1	0	0	0	1	0	0	0
3	1	0	0	0	0	0	0	0
4	1	0	1	0	0	0	0	0
5	1	0	1	0	0	0	1	0
6	1	0	0	0	0	0	1	0
7	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0

TABLE .1 COMMAND WORDS FOR EXAMPLE SEQUENCE

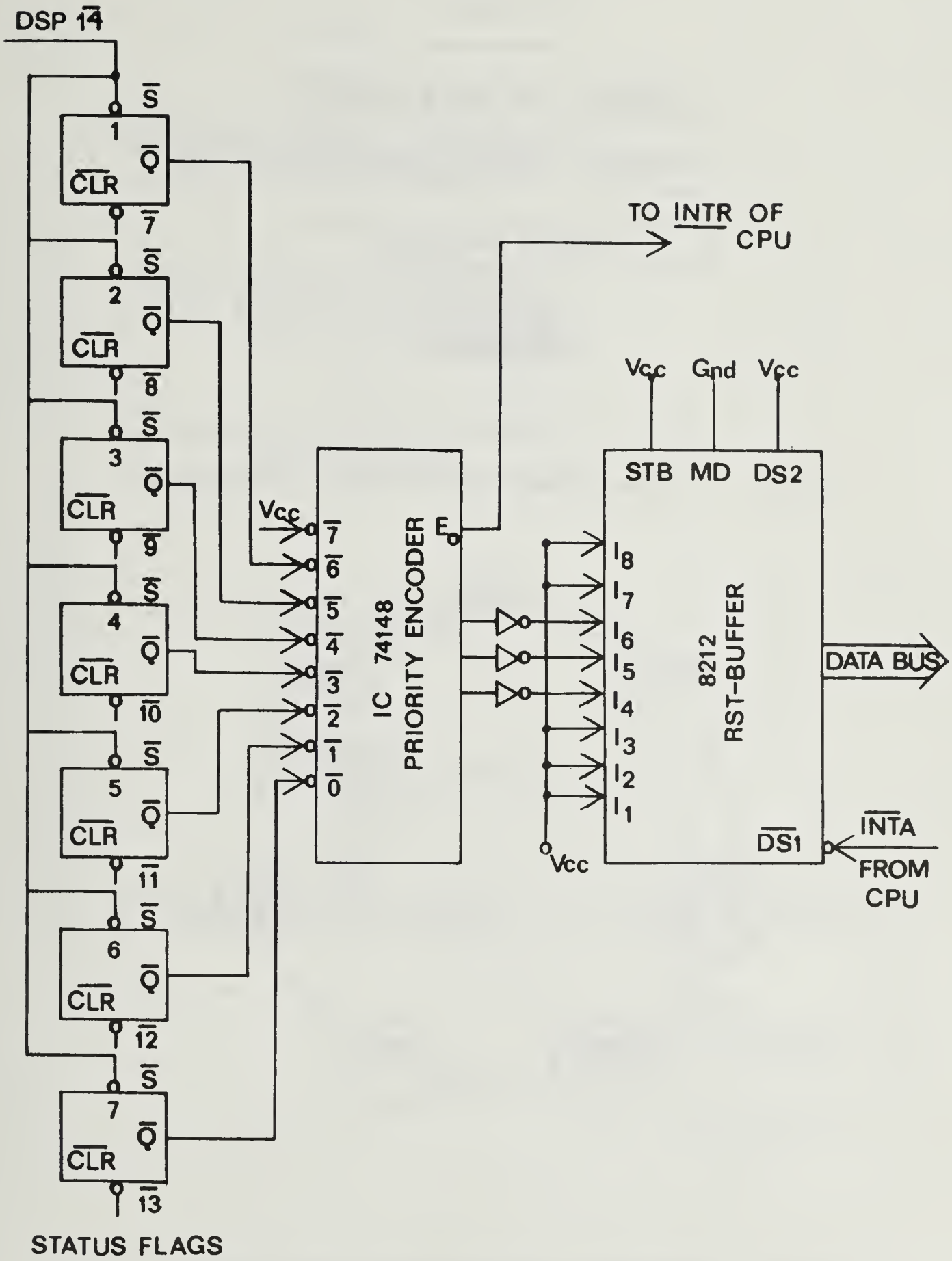

FIG.6 INTERRUPT INTERFACE

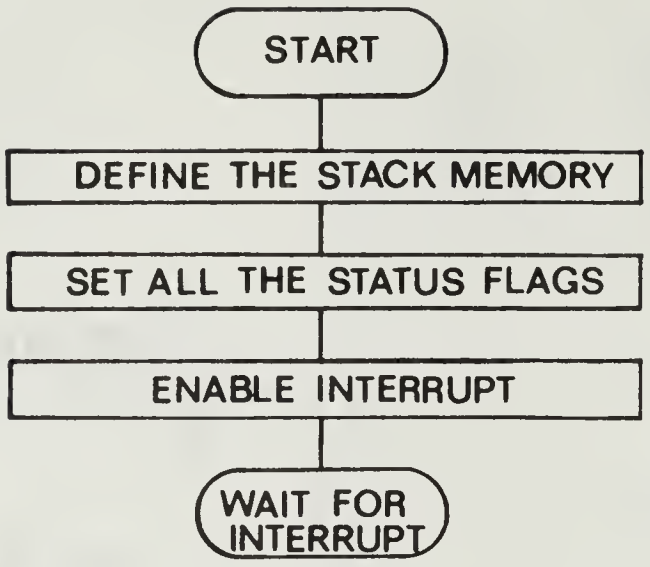

FIG. 7 FLOW CHART FOR POWER-UP ROUTINE

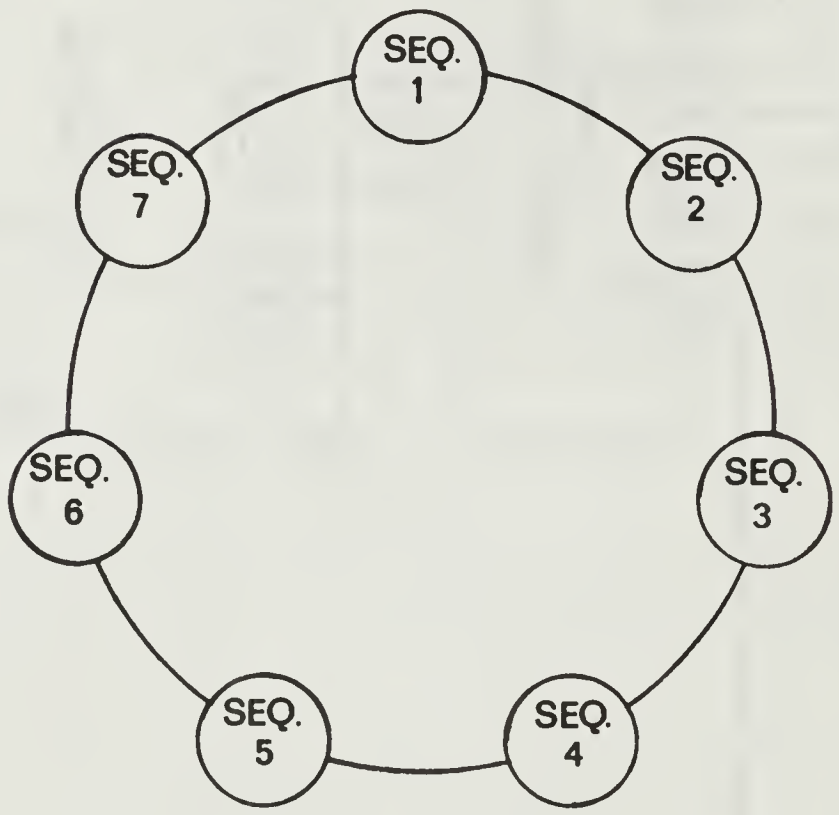

FIG. 8 SEQUENCE TRANSITION IN THE CYCLE

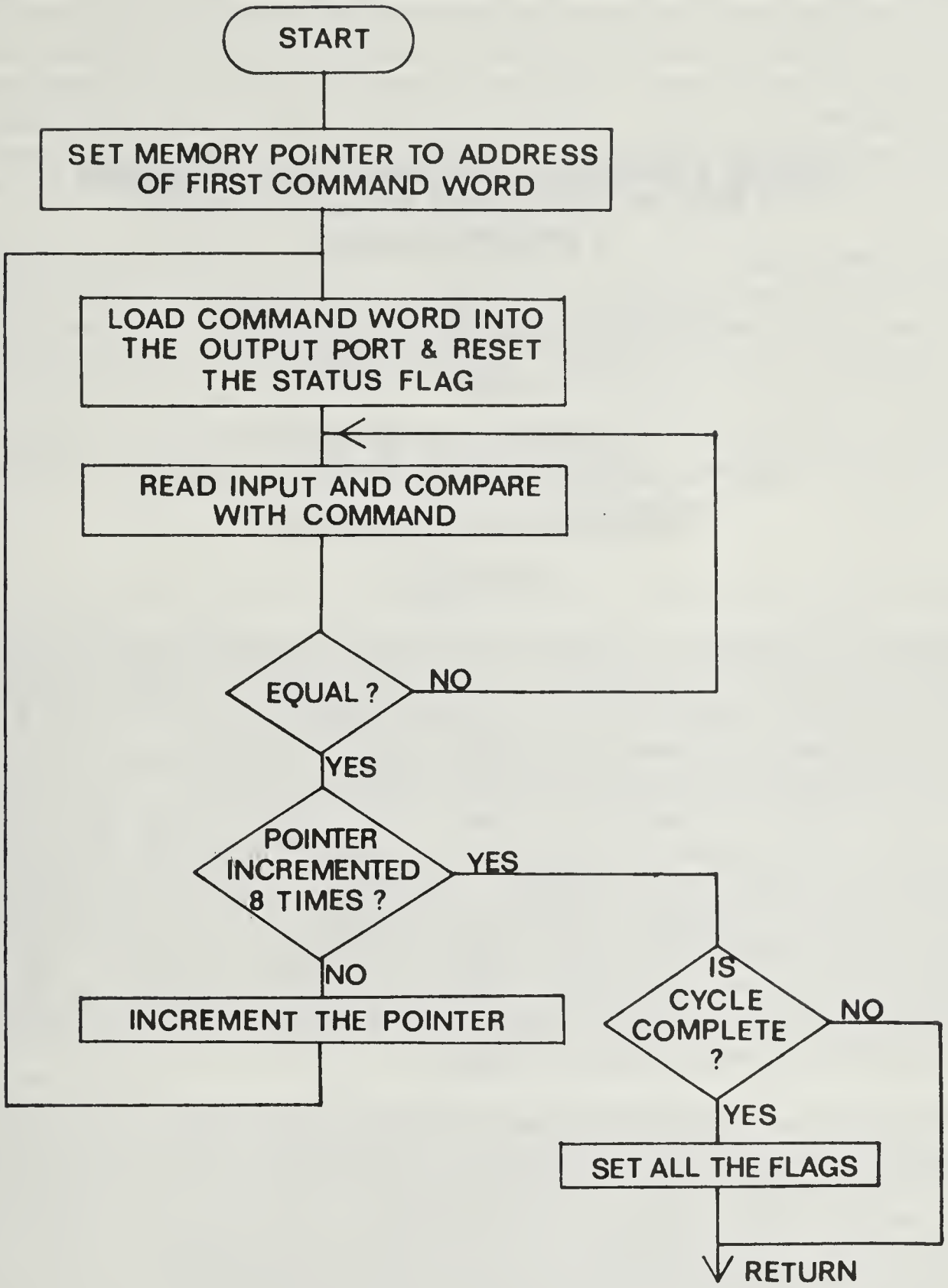

FIG. 9 FLOW CHART FOR TRAP ROUTINE

A MODEL SYSTEM FOR COMPARING HOST RESPONSES TO MULTIPLE INFECTIONS ON INTACT ONIONS I. EFFECTS OF LIGHT

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ABSTRACT

Fleshy leaf-bases of white, yellow, and red onions were exposed to ambient air and inoculated at 3 locations with Colletotrichum dematium *var* circinans *and* Botrytis allii *before incubation in light or dark. Other areas, on the same bulbs, were puncture wounded without inoculation, or not treated after exposure. Largest lesions were produced by* B. allii. *On tissue incubated in dark, lesions produced by* B. allii *were larger than those produced on tissue exposed to light. The converse was true for lesions produced by* C. dematium *var* circinans. *Basal portions of bulbs were less susceptible than equatorial and apical regions of all bulbs. The pH of lesions induced by these pathogens was significantly lower (range, 3.9 to 5.3) than that of uninfected tissue (pH 5.9). In areas adjacent to lesions, pH was generally unchanged from the norm (range 5.2 to 5.9). Wounding did not affect pH. Tissue pH (lesion or adjacent) was not affected by presence of light. Most nuclei in cells adjacent to lesions moved toward the infection. More nuclei moved toward* B. allii *lesions than* C. dematium *var* circinans *lesions. Nuclear movement was not related to lesion size, lesion pH, section of bulb inoculated, or presence or absence of light.*

The outcome of a host-parasite interaction is dependent on many external variables, as well as the physiologies of the host and the pathogen and their responses. Presence or absence of phenolic compounds, in outer dry leaf-bases of onion, are important in determining host response to infection (Link and Walker 1933, Clark and Lorbeer 1975). Once the protective layers (dry leaf-bases) are penetrated inner tissue susceptibility to infection increases (Hatfield *et al.* 1948). Exposure of underlying leaf-base epidermal tissue to ambient air increases nuclear dry mass, nuclear RNA, and nuclear protein over a 48 hr period, with attendant increase in nucleolar size (Courtis and Pappelis 1977 a, b). These reactions are interpreted as activation of quiescent cells due to exposure, and are accompanied by increased levels of caffeic and chlorogenic acids, and increased resistance to spread of *Botrytis allii* (Somasekhara 1974). These studies were limited to 48 hrs following exposure and were carried out in the dark, as were all studies of host-pathogen interactions conducted by Kulfinski and Pappelis (Pappelis *et al.* 1974, Kulfinski and Pappelis 1976).

Pappellis *et al.* (1976) reported that caffeic and chlorogenic acids inhibited germination of *B. allii* spores at pH levels found in onion bulb tissue. Tichelaar (1967) reported a pH gradient exists between colonized and uncolonized tissue, extending through several rows of cells in advance of hyphae. This gradient may affect activation of host phenols and fungal metabolism. Clark and Lorbeer (1975) reported that mycelium was not inhibited by levels of phenols that was found by Somasekhara (1974) to inhibit germination of *B. allii* spores.

Reports on onion physiology and the physiology of onion pathogens are common (Walker and Lindegren 1924, Walker and Stahman 1955, Kulfinski and Pappelis (1971). Light influences fungal pathogenicity (Link and Walker 1933, Venateswarhu and Sirohi 1974, Antenhill and Nicholson 1978), yet studies on the physiology of host-pathogen interactions on onion, especially

in light, are infrequent. The onion-pathogen interactions can serve as model systems under various conditions of storage, temperature, presence of gases, relative humidity, and light so that lesion development, nuclear movement in host cells, pH shifts, synthesis of fungitoxic compounds by the host, and synthesis of toxins by the pathogen in response to infection can be better understood.

The purpose of this study was to determine the effect of light on three variables (lesion size, tissue pH, and nuclear movement in tissue) following exposure of turgid leaf-bases to the ambient atmosphere, and inoculation with *Colletotrichum dematium* var *circinans* (Berk.) v. Arx and *B. allii* Munn.

This study was undertaken by students in Introductory Plant Pathology as part of an effort to incorporate the process skills used by scientists into the classroom laboratory. The introduction of process skills training into several university classes, greatly aided the improvement of problem solving by undergraduates and graduates majoring in science or non-science specialties (Pohlman and Pappelis 1977, Pappelis *et al.* 1980). "Hands-on" approaches to pest management and research techniques in plant pathology classes are gaining acceptance (Garrett *et al.* 1980).

This manuscript represents the success of these students in a guided group research effort.

MATERIALS AND METHODS

White, yellow, and red onions were obtained from local, commercial sources in 50 lb lots for use throughout these experiments. Varieties were not known. However, it has been shown that repeatable results could be obtained on otherwise like onions, *i.e.* bulbs having the same color and size and being free of damage or disease (Pappelis *et al.* 1974, Mayama and Pappelis 1977, Kulfinski and Pappelis 1978). Bulbs were stored in the laboratory in mesh sacks, simulating commercial storage. Only bulbs 8 cm in diameter, free from injury and disease, were selected for study. All dry leaf-bases were removed from selected bulbs to expose turgid leaf-bases. Bulbs were then rinsed with deionized water before treatment.

Four treatments were applied to each bulb. These were: exposure to ambient atmosphere without wounding or inoculation; exposure with wounding; and exposure with inoculation with both pathogens, *B. allii* and *C. dematium* var *circinans*. The same treatment was applied at three locations on each of four axes of each bulb. These locations were: 3 cm from the apex (apical); mid-point of the bulb (equatorial); and, 3 cm from the base (basal). Treatments and resulting lesions were always more than 2 cm apart so that little or no treatment interactions were expected (Kulfinski and Pappelis 1976).

To inoculate bulbs a sterile transfer needle was scraped across 10- to 14-day-old cultures, grown on white onion infusion agar, to accumulate spores. The infested needle was inserted into turgid leaf-bases to a depth of 0.5 cm. Pathogens were inoculated into bulbs at points 180 ° opposed to each other at each of the three points of inoculation (apical, equatorial, basal).

Wounding was performed using a sterile transfer needle inserted into turgid leaf-bases to a depth of 0.5 cm at points equidistant between inoculations. Tissue that was exposed, without wounding or inoculation, was located 180 ° opposite exposed-wounded tissue.

Treated white, yellow, and red onions were incubated at 24 ± 1 °C under continuous cool-white fluorescent light (Sylvania® , 1,133 lux, 320-750 nm) or in the dark for up to 7 days.

At 3 and 7 days, three of each bulb type were used to determine areas of ellipsoid shaped lesions. For each treatment short-range pH paper (pHydrion, Micro Essential Laboratory, N.Y., N.Y.) was inserted into an incision to determine pH. For lesions, a horizontal incision was made in the colonized tissue and 1 cm beyond the edge of the lesion. For wounds (punctures in exposed tissue), pH was determined in incisions made horizontally through the wound. For exposed tissue, a horizontral incision was made midway between the two adjacent inoculation treatments and on the side opposite wounds.

For histological observations, pieces of leaf-bases, approximately 2 cm^2, including the wound site or edge of lesions, were removed and the lower (abaxial) epidermis stripped using forceps. The epidermal piece was immediately placed in FAA. Using flat-field light microscopy, nuclear position was determined in 20 cells in two vertical rows of cells adjacent to the wound or inoculation site. Tissue was stained with a dilute solution of methylene blue to facilitate viewing. Nuclear position was classified as being in the central longitudinal third of the cell, or in the third toward or away from wounds or inoculations. For control tissue, nuclei in the right hand third of the cell were arbitrarily assigned as ''side toward'' and in the left hand third of the cell as ''side away'' for comparison to nuclei in tissue adjacent to wounded or in fected tissue. Distribution of nuceli in control tissue was used as the base from which nuclei position (distribution) percentages for other treatments could be computed. Means for all treatments were tested statistically for differences using Analysis of Variance (a = .05) and by regression analysis (p = .05) (Barr *et al.* 1976).

RESULTS AND DISCUSSION

Lesion Formation and Size

Lesions were gray, water-soaked, sunken areas of tissue surrounding a puncture inoculation site. After 3 days of incubation, few lesions had formed in *C. dematium* var *circinans*-inoculated tissue. In the case of *B. allii,* lesions had formed at all inoculation sites except those in apical regions of red onions incubated in light. At the end of 7 days incubation, *B. allii* lesions were present in all inoculation sites except those of apical areas of red onions incubated in light.

After 7 days of incubation, lesions produced by *B. allii* were larger than *C. dematium* var *circinans* lesions on the same bulbs incubated under identical conditions. For *C. dematium* var *circinans,* lesions produced in light were larger than those in the dark. The reverse was observed for lesions produced by *B. allii* (Table 1).

In general lesions caused by both pathogens in white, yellow, and red bulbs, were smaller in basal inoculation sites than those produced at the apical and equatorial sites regardless of incubation regime (Table 2).

Clark and Lorbeer (1975) inferred that the reason symptons of *Botrytis* brown stain are more severe in the neck of the onion bulb is due to the lower concentrations of phenols in the neck (Walker and Stahman 1955, Clark and Lorbeer 1973) and in the shoulder of the bulb (Clark and Lorbeer 1975). Data presented here support these inferences since larger lesions were produced in neck (apical) and shoulder (equatorial) regions than in basal regions of bulbs of each color type for both pathogens studied.

Hammerschmidt and Nicholson (1977) indicated that lesion development of *C. graminicola* on corn is light-dependent. Responses recorded here for the two fungal pathogens of onion indicate that light and bulb location affect lesion size. MacLean and Tommerup (1979) determined that quality of light and length of exposure affected lesion development in *Poa pratensis* inoculated with *Drechslera sorokiniana*. Antenhill and Nicholson (1978) determined that dark treatment of corn, inoculated with *C. graminicola,* allowed for lesion enlargement due to lack of production of phenols that would normally be produced in light. This similar condition was reported for wheat rust caused by *Puccinia recondita* (Venateswarhu and Sirohi 1974).

Possible explanations for differences in lesion sizes due to exposure to light may be that 1.) inhibitors or stimulators are synthesized by activated host tissue (Somasekhara 1974, Courtis and Pappelis 1977a, b), 2.) effects on pathogens (no effect, stimulation, inhibition) are mediated by different concentrations of the compound(s), 3.) cells in the three locations (apical, equatorial, basal) are activated to different levels producing, or accumulating, different concentrations of the same substance, or 4.) different substances are synthesized in the different locations. Bhullar and Daly

Table 1. Mean lesion area (cm^2) for all lesions on white, yellow, and red onions inoculated with *Botrytis allii* and *Colletotrichum dematium* var *circinans* incubated in light and dark at 24 °C. Values represent means for three bulbs per onion scale color, each with six lesions *1/*, measured seven days after inoculation.

Pathogen	*Incubation Regime*	*Scale Color*	*Lesion Area*
Botrytis allii	Dark	Red	10.09a *2/*
		Yellow	4.00 b
		White	2.41 c
	Light	Red	3.41 b
		Yellow	3.08 bc
		White	1.90 d
Colletotrichum dematium var *circinans*	Dark	Red	0.04 f
		Yellow	0.61 e
		White	0.39 e
	Light	Red	1.01 d
		Yellow	1.20 d
		White	1.19 d

1/ 3 lesions per pathogen, 108 total lesions

2/ Values followed by the same postscript are not significantly different at the 5% level (SNK).

(1975) determined that light stimulated toxin production in *Helminthosporium maydis*. Light may activate synthesis of fungal toxins in *C. dematium* var *circinans* and inhibit synthesis of *B. allii*.

Tissue pH

Mean pH of control tissue throughout remained at 5.9 regardless of onion color. Wounding did not alter pH. After 7 days of incubation, the pH of tissue adjacent to lesions of *C. dematium* var *circinans* was the same as that for controls. Tissue adjacent to *B. allii* lesions at equatorial and basal sites of yellow onions incubated for 7 days in dark, and at equatorial sites of red onions incubated for 7 days in light had a mean pH of 5.4 (range, 5.2 to 5.5). This difference was statistically significant from that of controls.

Table 2. Mean lesion area (cm^2) for all lesions on apical, equatorial, and basal sections of onion for all leaf-base colors inoculated with *Botrytis allii* and *Colletotrichum dematium* var *circinans* incubated in light and dark at 24 °C. Values represent means for three bulbs per leaf-base color, each with six lesions *1/*, measured seven days after inoculation.

Pathogen	*Incubation Regime*	*Bulb Section*	*Lesion Area*
Botrytis allii	Dark	Apical	6.28a *2/*
		Equatorial	6.66a
		Basal	3.56 c
	Light	Apical	4.52 b
		Equatorial	3.14 c
		Basal	0.72 e
Colletotrichum dematium var *circinans*	Dark	Apical	0.64 e
		Equatorial	0.27 f
		Basal	0.14 f
	Light	Apical	1.37 d
		Equatorial	1.77 d
		Basal	0.27 f

1/ 3 lesions per pathogen, 108 total lesions

2/ Values followed by the same postscript are not significantly different at the 5% level (SNK).

Few lesions, which had developed after 3 days, showed shifts in pH. Where changes did occur pH values, although lower than those of control tissue (range, 5.7 to 5.8) were not statistically different. After 7 days, lesion pH was significantly below control tissue pH (range 3.9 to 5.3). Exceptions occurred in *C. dematium* var *circinans* inoculated equatorial and basal sites of yellow onions incubated in dark, and basal sites of *C. dematium* var *circinans* inoculated yellow onions incubated in light. Lesion pH in those areas was generally 5.8 (range, 5.6 to 5.8). There were no statistically significant changes in shifts of pH due to presence or absence of light, and shifts in pH were not related to lesion size ($r^2 = 0.23$).

Somasekhara (1974) reported a sharp transition of pH at boundaries of dark-induced *B. allii* lesions. This was the case here for both fungi incubated in light and dark.

Nuclear Movement

Nuclear distribution patterns for exposed wounded and unwounded tissue, and tissue adjacent to wounds and lesions, were consistent for tissue treatments over bulb locations, onion color, incubation regime, length of incubation, lesion size, and lesion pH. All means were combined for statistical analysis. The means for nuclear distribution: 1.) in uninoculated tissue and tissue adjacent to lesions were significantly different, 2.) in exposed and exposed-wounded tissue were not statistically different, and 3.) in tissue adjacent to *B. allii* and *C. dematium* var *circinans* lesions were statistically different. For exposed and exposed-wounded tissue, approximately 28% of the nuclei were located at the "side toward" and "side away"; 44% were located in the center of cells. For tissue adjacent to *C. dematium* var *circinans* lesions, about 50% of the nuclei were located on the "side toward" infection, about 19% on the "side away", and about 31% in the center of cells. For tissue adjacent to *B. allii* lesions, approximately 64% of the nuclei were on the "side toward" infection, 13% on the "side away", and about 23% in the center of cells.

It is accepted that onion bulb color is a stable genetic character. This study established that a model system for studying host responses to multiple infection, with comparisons made to genetically identical control tissue on the same intact bulbs is feasible, and that responses between color groups (white, yellow, red) vary. It is expected that further experimentation may indicated differences for measured responses within varieties of a particular color group.

Specifically, this preliminary study has produced data which indicate that 1.) light plays a role in development of lesions in onion tissue infected with *C. dematium* var *circinans* and *B. allii,* 2.) that different locations on bulbs (basal vs apical or equatorial) can be used to study response capacities of the host, and 3.) two or more pathogens can be studied and compared to uninfected tissue on the same bulb. However, many more questions on the effect of some variable of light (wavelength, time of exposure, intensity) on host and pathogen metabolism need further study. Using the model, studies of host-pathogen interactions with other variables (*i.e.* temperature, presence of gases, and relative humidity), can be undertaken to clarify the mechanisms of lesion development, pH shift, and nuclear movement in a host that is well known for the involvement of phenolic compounds in the resistance mechanism.

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Foraging Behavior of the Honey Ant *Myrmecocystus mexicanus,* in Colorado

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ABSTRACT

Five nests were observed over a four year period in the Colorado Springs area for periods up to 453 days to determine the method of foraging of the honey ant, Myrmecocystus mexicanus, *and the nectar sources utilized to fill swollen storage ants in each colony, called repletes. Honey ants forage at night at temperatures ranging from 0.6 to 27 C between March and November. The maximum foraging distance was 19.8 m and the rate of progression varied from 0.28 to 0.94 m/min. At times workers forage on poorly defined trails and at other times in a diffuse pattern. Workers gather nectar from Cynipid galls on scrub oaks, from yucca capsules, and occasionally from aphids. They also scavenge dead insects and arachnids. Notes on predation and interactions with other ants are also represented.*

INTRODUCTION

Although the foraging activities of the nocturnal honey ant, *Myrmecocystus mexicanus,* have been discussed by a number of investigators (McCook, 1882; Wheeler, 1908; Slocumb, 1966 and Snelling, 1976) this paper attempts to reexamine, discuss, and extend their findings in light of data collected in Colorado Springs. This site was chosen since it was the location of McCook's original investigation of this species.

Five nests were observed for periods of 52, 100, 422, 422, and 453 days, and many other colonies were watched for much shorter periods of time. The evening observations were made by the light of a double-mantle Coleman lantern and were useful in ascertaining the method, speed, duration of foraging, and maximum distances traveled. Seasonal activity and climatic effects on foraging were noted. Information was also obtained on nectar sources, carnivorous habits, predation, and interactions with other species of ants. All times were expressed as Mountain Standard Time.

RESULTS AND DISCUSSION

Method of foraging

Usually a number of workers assemble on the crater each evening about sunset before moving off to forage. But sometimes the early exodus failed to materialize due to too few ants emerging, or emerging but not leaving the crater, or emerging but then retreating back into the entrance again. Surprisingly, all nests observed for any period of time exhibited a complete lack of early-evening foraging on a number of nights. For example, at one colony the early-evening exodus did not occur on 23 evenings between July 3 and October 4. However, on three of these occasions, the ants were seen foraging later in the evening, or early the next morning. At another colony, foraging activity was very weak to nonexistent on ten evenings between May 9 and September 10, and at a nest in the Garden of the Gods, no foraging occurred during five early vigils (7-8 PM) between June 6 and 17.

Although honey ants from a given colony forage in various directions during the year and at times exhibit a diffuse searching pattern, at other times they march off in one direction leading to a nectar-bearing plant night after night. For example, the workers of one colony marched to a scrub oak thicket, 10.4 to 10.7 m south of the crater, 22 times between June 26 and August 29. On these evenings the ants streamed south on a worn pathway and reached the trees between 7:58 and 8:35 PM. They often stopped and regrouped in small clearings before resuming their march, and sometimes a few workers began to return to the nest only five minutes after having left. Occasionally, they even reversed their main line of march, as on June 4, when they advanced 76 cm southwest of the crater, then returned seven minutes later, and went off on a northerly course.

These findings contradict Snelling's (1976) observations that there are no foraging trails as such, and that the workers radiate in all directions before finally arriving at previously visited food sources.

The trails generally follow bare ground and do not go through dense grass or other vegetation. The paths are certainly not as definitive as those of some species of ants and show no evidence of construction. As McCook (1882) noted, the trails wind somewhat and seem to avoid surface inequalities.

As mentioned, the advance workers of the column stop and regroup periodically in small clearings before resuming the march, but there appears to be no definite leadership on the trail. McCook (1882) also stated there were no leaders, but then contradicted himself by noting on one occasion that a dwarf led most of the way, until a worker-minor finally took over as head of the column. The two were separated from each other and the main column by about 20 to 25 cm.

It is doubtful that honey ants leave a scent trail, since they were not seen pressing their abdomen tips to the ground, but how they navigate is unknown. Lantern light did not seem to disorient ants on the trail, and a rock placed in their path only confused a few momentarily; most went up and over the obstacle.

When honey ants visit two or more nectar sources in the same general direction, the trail may bifurcate a short distance from the entrance. For example, in the nest discussed previously, the ants not only visited oaks 10.4 to 10.7 m south of the crater, but also went to oaks 9.8 m southeast of the colony. The path to the southeast branched from the trail south a short distance from the entrance. At another nest, the trail forked 69 cm east of the nest, one path going south while the other headed east.

Honey ants may also switch nectar sources during two consecutive years or even within the same season. As noted, ants from the nest above mainly visited the two yuccas 19.9 m north of the crater during the second year, but in the year previous they exploited yuccas in several different locations as well. They were on the yucca closest to the nest, 0.9 m north, on August 6 and 8. They visited a yucca 10.1 m to the east on July 18 and August 8. They were on a yucca 11 m to the southeast on July 21, and on another 16.8 m to the southeast on July 18 and 21. And once, on July 21, they were observed on a yucca 23.6 m to the south, although it is not certain that they emanated from this nest.

The nests observed foraged mainly on yuccas or scrub oaks, but not both. Whether the exclusive utilization of one plant species during the season is the norm is not known, but it would appear not to be from what others have reported (see section, Foraging on Other Plants).

At other times, honey ants from a given nest went off in several directions simultaneously, and not in well-defined columns. Presumably they used this diffuse-foraging pattern either to scavenge for dead arthropods or to locate nectar-producing plants.

Duration of foraging

Myrmecocystus mexicanus does most of its foraging between sunset and sunrise. The initial activity begins slowly with the emergence of one to four workers, apparently in response to lowered light intensity. The first ant out is almost as likely to be a small worker as a major and it was noted that workers of all sizes subsequently forage.

The first worker came out at times ranging from 5:45 PM on October 7 to 7:57 PM on July 14, but usually between 7:18 and 7:49 PM, except at the time of swarming when emergence occurred somewhat earlier (6:54 to 7:05 PM). On the average, the first ant came out at 7:30 PM.

The principal activity of the evening occurs when the workers mass on the crater and/or begin to leave in numbers to forage. Ants are often sluggish when they first emerge from the formicary, but gradually become more active as night falls and their numbers increase. The main exodus occurred at times ranging from 5:50 PM on October 7 to 8:13 PM on July 16, but generally between 7:22 and 8:13 PM. The average time of the main exodus was 7:46 PM. Thus, the time between the appearance of the first worker (7:30 PM) and the mass exodus (7:46 PM) averaged 16 minutes.

Sometimes workers returned to the nest shortly after the mass exodus. For example, ants left one nest at 7:40 PM, and by 7:45 PM several were already coming back.

But typically, ants returned later in the evening, often with a major influx occuring just before sunrise. Nevertheless, some ants were observed leaving the nest even as daylight approached. Several were seen going out a short distance as late as 4:50 AM, and on June 16, at 5:43 AM, a small worker marched off 3.4 m before she was lost from view. McCook (1882) reported that *mexicanus* workers begin to return about midnight and continue until 4 or 5 AM.

Maximum foraging distances

The maximum foraging distances for the nests in my study ranged from 8.8 to 19.8 m (possibly 23.6 m). McCook (1882) noted ants out as far as 15.2 m and Slocumb (1966) reported that workers would travel up to 32.9 m to feed on the plains east of Colorado Springs, although distances of 15.2 to 24.4 m were more common.

Effect of climatic factors on foraging

Honey ants foraged at air temperatures ranging from 0.6 °C to 27 °C. Kay (1974) worked on the thermal physiology of several diurnal and nocturnal honey ant species near Las Cruces, N. Mexico and reported that *mexicanus* was not out of the nest at temperatures lower than 2 °C or above 30 °C.

Kay concluded that *mexicanus* can remain active at much lower temperatures than most desert ants and that the low temperature-tolerance of this species probably reflects an adaptation to nocturnal foraging since temperatures below 15 °C occur frequently at night in warm desert areas. This ability to forage at temperatures below 10 °C allows *mexicanus* to be active at night throughout much of the year in southern New Mexico and as late as November and as early as March in Colorado.

Kay (1974) noted that although nocturnal species have critical thermal maxima which are at the lower end of the range of diurnal species, they do not forage above 30 °C, well below the critical thermal maxima, and therefore rarely, if ever, encounter lethal high temperatures. Thus, while temperature sets upper limits on surface activity for diurnal species of *Myrmecocystus,* this is apparently not true for nocturnal species such as *mexicanus*. Thus, the limiting factor for the nocturnal species may well be light intensity, possibly coupled with temperature.

Other observations on temperature and humidity tolerances of honey ants by Kay (1974) are also of interest. In all species, the preferred temperature was higher during the hot summer months than at other seasons, suggesting some acclimation. And one curious finding was that the nocturnal *mexicanus* seemed less adversely affected by desiccation than the workers of the diurnal species.

Workers were noted on several occasions foraging in the rain, sometimes as far away from the nest at 19.8 m, but none were ever observed drinking water, even though they were on leaves covered with rain drops. Therefore, the source of water for the swollen aquapletes reported by Snelling (1976) and chemically analyzed by Conway (1977) remains unknown.

Effect of lantern light on foraging

Since most investigators, myself included, have used lanterns to observe the nocturnal activities of *mexicanus,* the effect of the light on its behavior is of interest, but unfortunately remains rather enigmatic. Lantern light sometimes disrupts foraging behavior, but at other times does not seem to affect it. Workers carrying prey far from the colony were sometimes disoriented by the light and took a long time to return or even went away from the nest. However, when a dead insect was being transported close to the crater, the worker generally brought it directly to the entrance despite the lantern's presence.

Lantern light did not seem to disorient the ants moving along trails, but McCook (1882) reported just the opposite, namely that it did disturb workers in the column and that they would go toward the lantern as it sat on the ground near the trail.

Sometimes lantern light caused workers on the crater to withdraw into the entrance, particularly if they had recently emerged, but at other times it seemed to have no effect. McCook (1882) reported that sentries around the entrance were always more or less excited by the light, and that he had to delicately manipulate the illumination to preserve natural behavior.

Seasonal activity

Workers foraged as late in the fall as November 7, and as early in spring as March 17, but were more active in the summer months of June, July and August. It was also noted that nests in the same area may exhibit different degrees of activity on any given evening.

Foraging on scrub oaks

Honey ants foraged on scrub oaks *(Quercus gambellii* Nutt.) in the vicinity of three nests at distances of 9.8 to 13.4 m. McCook (1882) observed workers going in a column to a thicket of scrub oak 15.2 m from the colony.

Workers generally visited the oaks between July 7 and August 29, but were sighted on trees around two colonies as early as May 26. McCook (1882) also mentions honey ants on scrub oaks in July and August, but did not give specific dates.

Honey ants may forage on oaks in two different locations at the same time. Ants from one colony visited an oak thicket 10.4 to 10.7 m south of the crater 22 times between June 26 and August 29, but also went to oaks 9.8 m southeast of the crater on seven occasions between July 9 and August 29.

Sometimes ants from a colony visited both yuccas and scrub oaks, but did not feed on the oaks. Ants from one nest were on oaks 13.4 m southeast of the colony only on May 26 and August 4 of two consecutive years, but did not feed on galls. At another colony there was only one observation, on May 26, of a worker on scrub oaks 12.5 m to the northwest, but again no galls were present and the rest of the time the ants fed mainly on yuccas.

Workers left the colonies for the scrub oaks between 7:22 and 8:10 PM, or approximately the same times, 7:30 and 8:00 PM, reported by McCook (1882).

Only the honey ants from one nest were ever observed feeding (Fig. 1) on the clear sweet droplets on reddish oak galls, and only between July 9 and August 13. These data contradict McCook's (1882) original study which seemed to suggest that gall nectar was the main source of carbohydrates for the species. The workers' abdomens visibly inflated while imbibing the gall nectar and the swollen ants returned to the nest.

The ants covered distances of 9.8 to 13.1 m to reach the oak galls and their rate of progression ranged from 0.28 to 0.88 m per minute, or an average of 0.55 m per minute. McCook (1882) reported that honey ants visited the same oak tree repeatedly and covered the 15.2 m to it in 17 minutes, for a faster speed of 0.90 m per minute.

When the ants reach the oaks, they fan out over the trunk, branches, and leaves, and finally seek out the reddish-brown galls, the work of the gall wasp, *Holcaspis perniciosus* (Cynipidae). The galls are usually in groups of two or more along the branches and gradually exude small droplets of clear nectar. McCook (1882) pointed out that the galls give off at least three series of exudations

Fig. 1. Honey ant drinking clear nectar droplet on Cynipid gall on scrub oak *(Quercus gambellii)* southeast of *Myrmecocystus mexicanus* nest (2.5X).

during the night, which explains the continual flitting of the ants from branch to branch and gall to gall. The successive exudations also invite the frequent return of workers to the galls from which they had formerly fed. The galls gradually dry up and by October the nectar is no longer flowing.

Wheeler (1910) believed that the secretions of the galls furnished only a portion of the food, and that most of their honey was obtained from the coccids and aphids on the oaks and other plants in the vicinity. Unfortunately, this speculation has not been confirmed by my field observations. Workers were never observed feeding on coccids and aphids on oaks, and only rarely on aphids on yuccas. But Hutchins (1962) did report that his wife once trailed a foraging column to a wild rosebush and saw them ''milking'' a herd of aphids, or plant lice, in addition to feeding on scrub oaks.

Foraging on yuccas

Honey ants visited yuccas *(Yucca glauca* Nutt.) in the vicinity of four nests between June 20 and August 10, but most often during the month of July. Workers were observed on plants as far as 19.8 m (perhaps 23.6 m) from the colonies. Data from one nest indicate that the ants covered the 19.8 m in 21 to 51 minutes on different evenings, and hence their speed ranged from 0.39 to 0.94 per minute, or an average of 0.62 m per minute.

Honey ants from one colony shifted their foraging pattern during successive years. During the first year they visited a number of yuccas in different locations (see Method of foraging), but during the second year the workers foraged primarily on two yuccas north of the nest.

Fig. 2. *Myrmecocystus mexicanus* workers (upper one distended) scraping surface of a green yucca *(Yucca glauca)* capsule 19.8 m north of the colony (3.1X).

The first workers to reach the yuccas often scale the spiked leaves or grass at the base before finding the main stalk bearing the capsules. Once on the green capsules, they move about and seem to secure nectar by scraping the surface, or licking already injured areas (Fig. 2). Once, on July 18, the workers appeared to be feeding on small whitish objects on the capsules which may have been coccids.

Honey ants can exploit the yucca capsules only during a short period in the summer. Yuccas were in full bloom on June 20, but their capsules began to dry up as early as July 21, and by mid-September they were shriveled and dehiscing, and therefore useless as a nectar source.

Workers from two colonies were observed on yuccas infested with aphids on four occasions between June 20 and July 21. (Fig. 3). And although they drank aphid honeydew, they were never observed actually ''milking'' the insects.

The amounts of honeydew produced by some aphids are prodigious, with outputs ranging from 1.9 to 133% of body weight per hour. When unaided by ants, the aphid disposes of the droplets by flicking them away with its hind legs, or cauda, or by expelling them by contracting its rectum or entire abdomen. Many ants collect this honeydew from the ground or vegetation where it falls (Wilson, 1971). This phenomenon might explain the presence of some of the droplets on the yucca capsules which the honey ants are so fond of.

Fig. 3. *Myrmecocystus mexicanus* workers tending aphids on a yucca *(Yucca glauca)* capsule. Note drop of honeydew suspended from rear end of aphid (arrow) (2.1X).

Foraging on other plants

Since McCook's original in-depth study, many other plants have been implicated as nectar sources besides scrub oaks. However, the ants in my study fed only on scrub oaks and yuccas. Occasionally they were observed on cacti and grass, and, on rare occasions, they brought back a small flower or seed-like objects.

Slocumb (1966) saw plains honey ants utilizing many species of plants, such as the leaves and stem nodes of *Lupinus plattensis* Wats, the nodes of *Psoralea lanceolata* Pursh, *Chrysopsis villosa (Pursh) Nutt. = Heterotheca villosa* (Pursh) Shinner, and the nodes of the New Mexican Prickly Pear Cactus, *Opuntia phaeacantha* Engelm. He also saw workers crawling on blue grama grass, *Bouteloua gracilis* (H.B.K.) Lag., but never observed them feeding on it. He concluded that honey ants feed on almost any plant in their environment, and although there are some they favor more for the amount of nectar that can be collected, or the flavor, if one plant is missing they can change their feeding habits and utilize a wide variety of plants.

Cazier and Statham (1962) reported *M. mimicus* feeding on or gathering the pollen and nectar from at least two plants in October and November, *Parthenium incanum* H.B.K. and *Euphorbia albomarginata* Englm., and they may have been getting honey-dew from aphids which were abundant on the underside of the leaves of the latter plant. During August and September they were observed carrying animal booty and were not found on flowers, even though many plants were in full bloom. It may be that in late fall the ants fill the repletes with nectar as a winter supply of food, or they might be filling a newly developed batch of repletes for this purpose.

Leonard (1911) reported the workers of *M. mojave* feeding on the exudates of flowers of the California pepper-tree, *Schinus molle,* on *Euphorbia setiloba,* on *Echium simplex,* a cultivated flower, and from the blossoms of the fragrant wild shrub, *Ceanothus cuneatus.* At other times he

found workers "milking" aphids upon roses and carnations at night. He felt it probable that almost all the wild flowers are visited by the foraging ants. But like other investigators, he found evidence of non-foraging at certain times, as when an *Echium simplex* in full bloom 8.2 m from the nest, was not exploited for three weeks.

Most recently, Snelling (1976) observed *mexicanus* taking juices from bruised or broken fruits, such as those of cacti *(Opuntia* spp.) and also nectar from a wide variety of flowers and extrafloral glands. He feels that perennial and annual desert plants are a very important nectar source, but that the ants also derive much nourishment from the exudates of aphids and pseudococcids. On several occasions he also saw *mexicanus* collect dry head-capsules from the chaff piles of *Pogonomyrmex* spp.

One unusual nectar source was the report by Shields (1973) of finding *kennedyi* tending larvae of *Philotes rita pallescens* (Lepidoptera: Lycaenidae) on flowers of *Erigonum kearneyi* var. *kearneyi* in Nye Co., Nevada. The ants also fed in the flowers.

Foraging on sweet solutions placed near nest

The communication of the food source between workers is not clear. When blue sugar water was placed on a glass slide a few centimeters from a *mexicanus* entrance, many workers clustered around it within several minutes. The first few individuals drank, developed swollen blue abdomens, and then gradually returned to the nest, where they excitedly bumped into nonswollen workers on the crater. Later several ants with blue abdomens emerged again and returned to the sucrose solution a second time.

At another nest, workers were given diluted bee honey on green leaves near the crater. But this time, the ants seemed to come to the honey by chance, and did not appear to communicate the location of the food source to others.

Other authors have commented on the reaction of honey ants to bee honey placed close to the nest. Leonard (1911) smeared a little bee honey on a piece of glass near a *M. mojave* nest. The honey was quickly surrounded by 40 to 50 ants who climbed upon each other to reach it, and in two or three minutes were fully loaded and staggered off towards the nest. They were willing to regurgitate when appealed to on their way back by a worker.

Slocumb (1966) reported that *mexicanus* can consume its food more efficiently if it is spread over a larger area. A feeding dish with a drop of bee honey concentrated in the center, attracted only three or four workers. But if the drop was spread out, as many as 30 ants could feed on it.

Insectivorous and carnivorous habits

Most investigators have noted that honey ants are primarily scavengers on dead arthropods, and that this prey constitutes an essential component of the total food supply. The fact that McCook (1882) did not, is perhaps the most glaring omission in his famous study.

Honey ants brought dead arthropods to every nest observed for any period of time, and were seen carrying prey from April 19 to October 22. Dead arthropods are also commonly scattered among larvae in excavated formicaries, and probably serve as essential protein and fat for brood development. In fact, larvae have often been observed feeding on dead insects (including honey ant workers) in artificial colonies.

The booty brought back to the nests was diverse and included many unidentified arthropods and fragments, as well as the following: Hemiptera (one Nabidae, one Lygaeidae), Homoptera (one Psyllidae, one Membracidae, one Cicadellidae, and one Aphidae), Orthoptera (two grasshoppers and two grasshopper legs), Diptera (a fly, a deer fly, and three mosquitoes), Coleoptera (unidentified beetles and one Curculionidae), Lepidoptera (moths and a caterpillar), Hymenoptera (ants, a small black wasp, and a bee exoskeleton), Arachnida (spiders and solpugids), larvae, and a leaf with a cocoon-like structure inside. The greatest number of insects and fragments brought to a nest in a given period of time occurred on June 4, when 23 were carried back between 7:23 and 9:00 PM.

Cazier and Statham (1962) also reported a diverse array of animal booty being brought back to the nests of *M. mimicus*. The prey included Hymenoptera (dead remains and one live bee), Orthoptera, Neuroptera, Hemiptera (some alive), Lepidoptera, Coleoptera (some alive), Diptera and Phalangida. There were also occasional pieces of feathers, seeds, leaves and flowers.

Snelling (1976) mentioned one unusual case where *mexicanus* was found actively feeding on dead rodents in traps in the Kingston Range, San Bernardino Co., Cal.

Usually each *mexicanus* worker transports a single insect or fragment, but occasionally two to seven cooperate to move larger prey. Four or five workers were seen carrying a live caterpillar, a dead moth and a grasshopper on different occasions, and, in one instance, it took seven ants to bring back a grasshopper. Workers are reluctant to part with their victim, and if they are picked up while transporting an insect, they will continue to cling to it, at least for a short time.

Although *mexicanus* is not an active predator and rarely attacks live arthropods, it will attack and kill small insects when the opportunity presents itself (Snelling, 1976). Workers were seen pursuing prey on several occasions. Once they were clustered around a small spider with a worker attached to it, and they sometimes chased ladybird beetles while foraging on yuccas. In another instance, they were around a beetle in the grass 86 cm from the nest.

Honey ants attempt to subdue their prey by grasping the victim in their mandibles and then spraying a fluid (formic acid) into the wounds, from a gland situated in the tip of the gaster. Leonard (1911) saw two caterpillars, 3.8 cm long and 0.6 cm in diameter, succumb to the spray in a few minutes before being dragged into a *M. mojave* nest.

Snelling (1976) reports that on several occasions *mexicanus* and *testaceus* workers did not carry back the freshly-killed insect, but rather masticated the corpse and then brought back the body fluids to fill a special type of replete, one filled with the juices of insect prey. This behavior was not observed in my study.

In addition to their normal fare, workers were also given disabled prey on a number of occasions which they attacked and took in. This supplemental sustenance included moths, solpugids, ants *(Camponotus vicinus),* small wasps, beetles (June beetles), damselflies, a fly, a mosquito and a small green inchworm. Some of these insects were attracted and injured by lantern light. When a large, gravid beetle was killed and placed beside one nest on August 16, the workers immediately took in the eggs. By August 22, the carcass was almost stripped, and only small brownish ants of another species continued to feed on the remains.

As mentioned, honey ants are not effective predators and have difficulty subduing prey. Often their quarry escapes, as when a velvet ant was twice put down a *mexicanus* entrance, and twice escaped and fled despite their assault. In another instance, when a large wood ant *(Camponotus vicinus)* was dispatched and put near the entrance, the honey ants at first alternately approached it and retreated. Later, when it was moved closer, the workers finally seized it and took it into the nest after nipping at it several times as if it was still a dangerous foe. Snelling (1976) noted that if the victim was much smaller than the ant, it was carried away, but if the prey was approximately equal to the ant in size and struggled, it was released and the honey ant darted away.

Predation on honey ants

Little predation on honey ants was observed during the four years of observation in Colorado. On July 8, a dead ant was found on the trunk of an oak, and on July 12, a spider (Fig. 4) was observed carrying a worker near a gall on a scrub oak. At another nest, a disabled worker came back to the colony at 5:01 AM on June 16. Honey ants on two occasions brought back dead nestmates and once carried back a worker injured by the author.

Others have recorded a few instances of predation by larger animals. Hunt (1973) found *Myrmecocystus* to be the prey of two lizard species, *Sceloporus occidentalis* and *Uta stansburiana,* in San Diego Co., Calif., based on examination of stomach contents.

Fig. 4. Spider carrying dead honey ant on a scrub oak *(Quercus gambellii)* south of nest *Myrmecocystus mexicanus* (1.3X).

Parks (1929) reported that the nests of *placodops* (reported as *melliger orbiceps)* are regularly dug out by the coyote, *Canis nebrascensis texensis* Bailey, throughout southwestern Texas, and Kay (1974) noted a nest of *mexicanus* dug out by a vertebrate in New Mexico in the spring of 1973. On a least one occasion, I also observed a nest dug out by some large animal.

Interactions with other ants

Honey ants were occasionally observed interacting with other ants close to the entrance. Small black ants (possibly *Dorymyrmex pyramicus* (Roger) were found around one *mexicanus* nest on several occasions; namely, July 6, August 10, 16, and 22 of one year, and on July 18, 21, and 26 of the next. They seemed to inhibit the dispersal of the honey ants, who were ringed around the entrance in what appeared to be a defensive posture. In one instance, a small black ant ventured into the entrance and disappeared, apparently due to seizure by a sentinel. But on another occasion, when the black ant wandered into the crater and made contact with a guard, it was the guard that withdrew into the entrance. The black ant did not follow, but left instead.

Others have also observed interactions between honey ants and *Dorymyrmex pyramicus*. Leonard (1911) reported that *M. mojave* tolerated *D. pyramicus* close to the nest. The black ants gathered around the honey ant nest to lap up honey he had put at the entrance, but there was no hostility expressed towards them. Cazier and Statham (1962) noted that raids by *D. pyramicus* would stop all outside activity and that *M. mimicus* workers would stay inside the nest entrance or

occasionally bring a piece of debris out onto the crater and then quickly retreat.

When a *mexicanus* trail crossed the entrance of a black ant colony, they chased the honey ants away whenever they ventured too close.

Large wood ants, *Camponotus vicinus,* interacted with honey ants and were found in the vicinity of a *mexicanus* nest on June 7, 8, 13, 15 and 19. The wood ants seemed to forage at will close to the honey ant crater, and at time headed directly for the entrance, or even wandered into it, before being chased away. But sometimes when a *vicinus* worker and honey ant came into contact close to the crater, the honey ant lunged, causing the wood ant to flee. Once a honey ant carrying a dead ant bumped into a wood ant, but then continued on unmolested.

Honey ants foraged on scrub oaks and yuccas with other ants and occasionally interacted with them. For example, both honey ants and small black ants (possibly *Dorymyrmex pyramicus)* drank clear droplets from the same oak galls, but never simultaneously.

Honey ants were seen foraging on yuccas with other ant species. On seven occasions, the members of one *mexicanus* colony were observed on yuccas with other ant species, and in four of these instances, the other species was a small black ant. The interactions with the other ants varied. In one case, the honey ant approached the alien worker, and then quickly retreated. Another time, the other species briefly chased the honey ant after their encounter. And finally, a honey ant collided with a black ant feeding on a droplet on a capsule, and both fled in opposite directions.

Observations on two *mexicanus* colonies showed that the yuccas closest to the honey ant crater were monopolized by small black ants and the honey ants foraged on more distant yuccas. For example, on July 6, the yuccas closest to one honey ant nest were occupied by small black ants, but on yuccas farther away there were small black ants, larger ants with a black head and abdomen and brownish-red thorax, and honey ants. There seemed to be a dominance hierarchy among the three species with *mexicanus* at the bottom. Upon contact, the small black ants chased the honey ants, but the former were in turn intimidated by the larger black and brown workers.

Honey ants were also observed on the same yuccas with two other species, *Camponotus vicinus* Mayr and *Crematogaster lineolata emeryana* Creighton, on June 20, but the other species were not as numerous as the honey ants. These species generally intimidated the honey ants upon contact, and at times even chased them.

The only direct evidence of interspecific confrontation occurred on September 30, when a small brown ant, *Myrmica sabuleti americana* Weber, was found clinging to the leg of a small honey ant about 1.7 m from the *mexicanus* nest. Honey ants also brought back dead ants of several species, such as *Camponotus vicinus, Formica fusca, Formica pallidefulva nitidiventris,* and *Dorymyrmex pyramicus,* but they may have been dead when the honey ants chanced upon them.

SUMMARY

Five nests were observed over a four year period in the Colorado Springs area for periods of 52 to 453 days to determine the foraging methodology of *Myrmecocystus mexicanus.*

The workers usually emerge and assemble on the crater each evening about sunset (7:46 PM on the average) before leaving to forage, but often the early-evening departure fails to materialize. Most foraging occurs between sunset and sunrise.

The maximum foraging distances around each colony varied from 8.8 to 19.8 (possibly 23.6) m, and the rate of progression averaged 0.55 m/min to 0.62 m/min.

Honey ants foraged as late in the fall as November 7 and as early in the spring as March 17, but were most active during the months of June, July, and August. They were out at air temperatures ranging from 0.6 C to 27 C, and in the rain. Light from the observation lantern sometimes disrupted their activity, but at other times did not seem to affect it.

Each nest exhibited both diffuse- and trail-foraging during the season. The diffuse-pattern is probably used to scavenge dead arthropods or to locate nectar-bearing plants. The trails are not as definitive as those of some ants, but they lead to nectar-bearing plants. Sometimes they bifurcate a short distance from the formicary and go to plants in two different locations.

Honey ants may return to the same plants during two consecutive summers, but they may also change nectar sources during successive years, or even within the same season.

Although most investigators report honey ants utilizing a variety of plants, the nests in the Colorado Springs area foraged primarily either on yucca or scrub oak, but not both.

Three nests foraged on scrub oaks *(Quercus gambellii* Nutt.) between May 26 and August 29, but only the workers from one colony were ever observed feeding on the sweet droplets exuding from oak galls, and then only between July 9 and August 13.

Honey ants visited yuccas *(Yucca glauca* Nutt.) in the vicinity of four nests between June 20 and August 10, but most often during the month of July. The workers sought out the green yucca capsules, and seemed to secure nectar by either scraping the surface of the capsules with their mandibles or drinking droplets already present. These droplets may emanate from injured areas on the capsule or from secretions cast off by aphids.

While other investigators have speculated on the importance of aphid honeydew as a carbohydrate source for this species, this did not prove to be the case in my study. Workers from two colonies were only observed on yuccas infested with aphids on four occasions between June 20 and July 21, and although they drank honeydew, they did not "milk" the insects.

Honey ants are primarily scavengers and bring back a diversity of dead arthropods to the nests. They were seen transporting prey from April 19 to October 22. Usually each worker carries a single insect or fragment, but on occasion two to seven ants worked together to move larger prey. Dead arthropods probably provide essential protein and fat for the colony, particularly for the developing larvae who are often seen feeding on them.

Honey ants sometimes attack live arthropods, particularly if they are small or close to the entrance. They grasp the victim in their mandibles and then bend their abdomens forward and spray fluid (probably formic acid) into the wounds. Larger, armored insects usually flee unharmed despite being repeatedly assaulted.

There appear to be a few natural predators on honey ants. Once a spider was observed carrying a *mexicanus* worker on a scrub oak and one nest was dug out by a large animal. Their greatest enemy in the Colorado Springs area is the realtor and developer since several nests were destroyed by new homes and restaurants.

Honey ants are usually intimidated by other species of ants, and often flee upon contact. Sometimes the yuccas closest to the nest were monopolized by another species and the *mexicanus* workers foraged on yuccas further away. Specifically, interactions were noted with *Dorymyrmex pyramicus, Camponotus vicinus, Crematogaster lineolata emeryana,* and *Myrmica sabuleti americana*. Honey ants also brought several species of ants back to the nests, but they were probably dead when the workers chanced upon them.

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NEW FRONTIERS IN THE ARCHAEOLOGY AND ETHNOHISTORY OF THE GREATER SOUTHWEST

Edited By

Carroll L. Riley and Basil C. Hedrick

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FOREWORD

This publication is the outgrowth of an invited symposium held at the annual meetings of the Society for American Archaeology in Tucson, May, 1978. The contribution of Dr. Washburn was written later, but specifically for publication with the symposium papers. Riley's article was orginally read at another symposium in Calgary, Alberta, but it fit the present theme so closely that we decided to include it with this collection.

The editors have chosen the New Frontiers Symposium to reinaugurate—after a long absence—the Anthropological Section of the Illinois State Academy of Science. Although the symposium deals with the anthropology of the Southwest, it seems to us that it is especially appropriate for inclusion in the *Transactions.* Seven of the nine contributors have close academic connections in the State of Illinois. Several were students at Illinois universities; in fact, three received their highest academic degrees in this state. At present, four of the contributors hold appointments in various Illinois universities and museums.

In a broad spectrum volume such as is implied by ''New Frontiers'', it is perhaps preferable, or at least useful, to have some overall theme or central focus. In organizing this symposium, we did not, delimit the nature of the contributions by individual authors. Nevertheless, all of the papers in the volume are, in fact, oriented to a theme. What all contributors did, to one degree or another, was to view the greater Southwest as an area in which cultural events were modified and enhanced by an interaction with the civilizations of Mesoamerica. In developing this theme, different authors took rather diverse courses. Reyman, Frisbie and Washburn see a strong Mesoamerican influx into the northern Southwest, particularly into Chaco Canyon. They use somewhat different sets of data to indicate their reconstruction of these influences, but their basic messages are much the same. Dutton takes a somewhat more indirect approach. She sees the Galisteo Basin of the eastern part of the Southwest as receiving strong influences in late pre-Spanish times from the south and west and suggests actual migration, as well as more indirect contact from southern New Mexico and Arizona areas. These influences, in turn, were part of a larger series of interactions that ultimately involved Mesoamerica.

Pailes, viewing things from the perspective of the Sonoran region, gives archaeological evidence to support Casas Grandes-Sonoran interaction and demonstrates how the Mesoamerican influence may have reached the Southwest. Riley's paper also, to some degree, deals with this area and, utilizing ethnohistorical evidence, he reaches much the same conclusion as does Pailes. The major thrust of Riley's paper, however, is the development of a methodological framework for attacking the problems of Mesoamerican-Southwestern contacts.

The Brookses, using very specialized material, looking northward into the Southwest, present evidence of trading activities linking Mesoamerica with the regions to the north.

A major conclusion that one can draw from the group of papers is that, at least at certain times in its history, the Greater Southwest did not stand alone, but partook—in greater or lesser degree—of Mesoamerican culture. It was, in other words, within the parameters of the Mesoamerican Great Tradition. At least a part of the ''New Frontier'' in future anthropological research in the Greater Southwest must surely be along the lines of further defining, exploring and analyzing this great cultural fact of life. As Mesoamerica was the center and the Greater Southwest the periphery we have logically arranged the papers geographically going from the south northward. Thus we start with the Brookses speaking from the outer core of Mesoamerica and end with Dr. Dutton on the far northeastern Galisteo plains and Pecos.

Our thanks go to the organizers of the Forty-Third Annual Meeting of the Society for American Archaeology. We also appreciate the support of our two institutions, Southern Illinois University and the Illinois State Museum. Special thanks go to Research Assistant Helmut Publ of Southern Illinois University and to Violet Jones and Helen Banaitis of the Illinois State Museum for their help in manuscript preparation. As always, in symposium publications, the editors owe a special debt of gratitude to the participants and authors of the various papers.

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December, 1978

CRANIAL DEFORMATION: POSSIBLE EVIDENCE OF POCHTECA TRADING MOVEMENTS

Sheilagh T. Brooks and Richard H. Brooks
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ABSTRACT

The archaeological significance of the limited occurrence in the Greater Southwest of skulls with tabular oblique or tabular erect cranial deformation may provide evidence of individuals traveling and trading from Nuclear Mesoamerica. At Casas Grandes few skulls with this type of deformation occurred, although symmetrical occipital deformation was common. In a site near Zape, Durango, Mexico, a semi-mummified skull was recovered exhibiting tabular oblique cranial deformation, including characteristically fronto-occipital flattening and lateral parietal bulges.

The archaeological implications of burials with this type of cranial deformation may relate to the movements of pochtecas *into the northwestern frontier along one possible trading corridor of the Sierra Madre Occidental. The inference is that skulls with tabular oblique or perhaps tabular erect cranial deformation are evidence of individual* pochteca *in an area outside of Nuclear Mesoamerica.*

DESCRIPTIONS OF MAP AND PLATES

Map: Shows the location of the cave sites within the Zape region, Durango, Mexico.
Plate 1: Right lateral view of Zape region tabular oblique deformed cranium.
Plate 2: Left lateral view of Zape region cranium.
Plate 3: Close-up of pre-mortem break and rehealing of nasal bones.
Plate 4: Lateral x-ray of Zape region, cranium, showing cervical vertebrae.
Plate 5: Frontal view of Zape region cranium.
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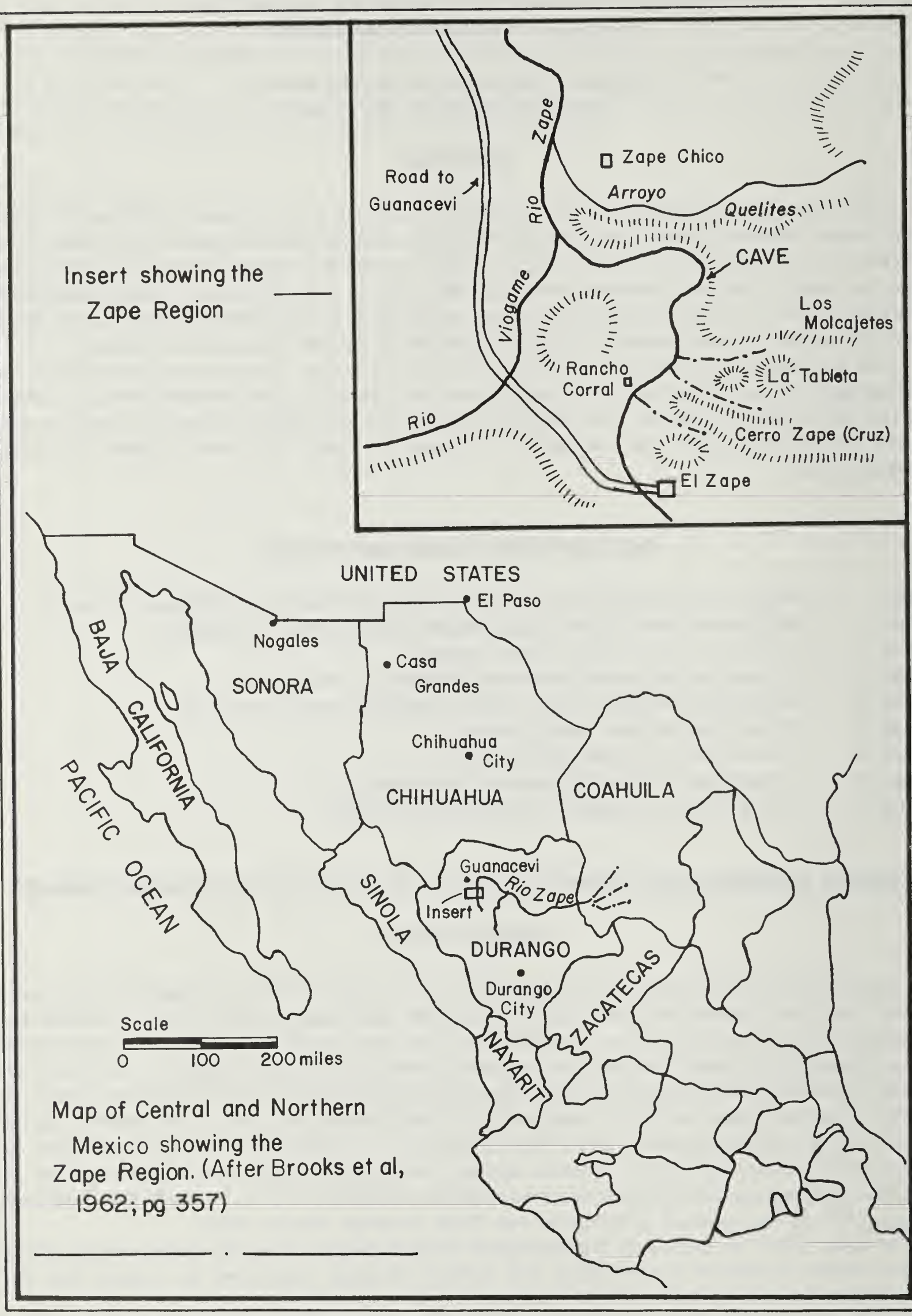
Plate 8: Lateral view of a Museo Nacional Zape area skull.

CRANIAL DEFORMATION: POSSIBLE EVIDENCE OF POCHTECA TRADING MOVEMENTS

INTRODUCTION

Recent discussions of the role of the *pochteca* in the cultural diffusion of Mesoamerican traits along the Sierra Madres into the Greater Southwest has raised questions as to whether the *pochteca* themselves traveled from core Mesoamerican urban areas, or whether the cultural diffusion extended northwards through local intergroup contacts. As Reyman states: ''. . . we have virtually no evidence for the prehistoric presence of the *pochteca,* per se, in the Southwest. That is, to date, no one has presented us with body warm or cold, at the sight of which can raise the chorus, 'Aha! Here is a *pochteca* member in the flesh (or skeleton)''' (1978:243). Reyman's comments on the need for direct physical, preferably skeletal, evidence validating the actual presence of pochteca themselves in the Greater Southwest elicited a recollection of an artifically deformed skull recovered from La Cueva de Dos Puertas near Zape, Durango, Mexico (Map).

In April, 1957, as part of an archaeological research project along the eastern slopes of the Sierra Madre Occidental in Chihuahua and northern Durango (supported by a grant from the



Map of Central and Northern Mexico showing the Zape Region. (After Brooks et al, 1962; pg 357)

Associates in Tropical Biogeography, University of California, Berkeley), R. H. and S. T. Brooks excavated a small cave near Zape Chico, Durango. Just prior to the start of this excavation, young boys removed at least two shallow mummified burials from an adjacent cave, La Cueva de Dos Puertas. Some of the materials they took to Durango City expecting to sell them. From the appearance of the midden surface after this vandalism, there had been several shallow mummy bundle burials within this cave. Human bones were scattered around in the vicinity of the area where the boys had disturbed the midden, as well as strips of rabbit skin (one item said to have been taken to Durango for sale was a ''rabbit skin serape''), cloth and basketry fragments. An artifically deformed, partially mummified, disconnected skull was lying on the surface with this scattered material. The human bones and other scattered items were reinterred and marked for future investigators.

The artificially deformed skull was later taken with data excavated from the small cave, La Cueva de Los Muertos Chiquitos, to the Instituto Nacional de Antropologia e Historia, Mexico D.F., as evidence of the archaeological potential of this large, relatively undisturbed site. As far as is known no additional excavation has occurred in La Cueva de Dos Puertas, although an archaeologist from the Instituto, Augustin Delgado, conducted further excavation of an adult burial in La Cueva de Los Muertos Chiquitos.

Considering this skull as a potential physical clue to the presence of a member of the *pochteca* in the Zape region, the actual evidence to be utilized is based on a cultural factor, the cranial deformation. Since the skull was found as a result of the boys' disturbance of the mummy burials, there was no archaeological provenience nor directly associated artifacts. In the two lateral views (Plates 1 and 2) the type of cranial deformation exhibited is unmistakably tabular oblique. The appearance of the Zape region skull laterally is identical with that of the cranium from Vera Cruz illustrating tabular oblique artificial cranial deformation (Romero, 1970:66), a trait that has been present in the Valley of Mexico since the Late Preclassic (Romero, 1970).

None of the burials from La Cueva de Los Muertos Chiquitos exhibit this type of cranial deformation. Further literature search has indicated that this variety of artificial deformation has a limited occurrence in northwestern Mexico and the Greater Southwest. On this basis it is proposed that tabular oblique or erect cranial deformation, which occur with relative frequency in the Nuclear area of Mesoamerica, might be an identifying trait indicative of a member of the *pochteca*. If this cranium does represent the buried remains of an actual *pochteca,* what are the cultural factors that would bring *trocadores* or merchant traders, themselves, into the Zape region.

PREHISTORIC TRADING POTENTIALS IN THE ZAPE REGION

On the eastern slopes of the Sierra Madre Occidental, Brooks (1978) has described archaeological sites encountered along the river drainage system of the upper Rio Nazas, which consists of the Rio Zape, Rio Tepehuanes and Rio Santiago forming the Rio Ramos and then flowing into the upper Rio Nazas (Brooks, 1978:map p. 84). Above these rivers on the bluffs, promontories and hill slopes have been located archaeological sites (Brooks, 1971; 1978) of what Kelley (1971) refers to as the Loma San Gabriel culture, which he considers a manifestation ot the Chalchihuites culture, extending from southern Durango to east-central Chihuahua. There is easy access into the Sierra Madres along this river system and the alluvial valleys prehistorically provided an agricultural potential that is still being utilized today. Both the Ramos and Zape regions contained population areas of sufficient density that they can be related culturally to the Chalchihuites urban centers, even through these areas are more on the level of developed villages and townsites (Brooks, 1978). In both these regions there are indications of religious centers, in which hilltops were used to simulate a pyramidal structure and several of these sites had locales that may be characterized as small associated playing fields.

In the Zape region there are numerous cave sites, which were used for habitation, in addition to the village sites on the mesa tops. Similar cave/shelters were not observed in other portions of the upper Rio Nazas drainage. The cave that was excavated in 1957, La Cueva de Los Muertos Chiquitos (Brooks, 1971; Brooks et al, 1962; Brooks and Brooks, 1978), produced artifactural material, mainly associated with the child burials, including olivella-type shells indicating trade with the western coastal areas. This may have been through direct contact or through an intermediary. In a cache towards the rear of the shelter two large ceremonial knives or lance heads were found—one made from white chert, the other from obsidian—and a low wooden stool carved in the shape of a turtle. Torquoise chips were embedded in pitch on a wooden pendant found in association with one of the child burials (Brooks and Brooks, 1978), and torquoise chips were encountered in several of the village sites during the survey of the Ramos and Zape regions. There is a radiocarbon date of ca. 660 A.D. (Brooks et al, 1962) derived from a single wood sample obtained from the lower levels of the midden desposit. During a discussion in 1964 Delgado, who had previously worked with Kelley at the Schroeder site, described the burial he excavated in La Cueva de Los Muertos Chiquitos as a Chalchihuites-type burial with associated grave goods.

The easy access into these regions of the upper Nazas drainage if from the east and south, and the cultural implications of the architecture and associated artifacts are oriented towards the more sophisticated Chalchihuites urban centers in southern Durango and northern Zacatecas. This is not to imply that there may not have been direct contact with the known prehistoric urban areas of the west coast, but the access is more difficult across the higher Sierran peaks and barrancas to the west. Kelley (1958) has noted similarities to west coast pottery and Chametla sherds at the Schroeder site, indicating established contact with that area. Trade routes may have been from west coast urban areas through to the Chalchihuites centers and then into the more remote regions where the Loma San Gabriel/Chalchihuites population densities occurred.

This brief discussion indicates that the Ramos and Zape regions had cultural connections through to the Chalchihuites centers in the south and that trading contacts appear to have existed. Under these circumstances it could be anticipated that a *pochteca* member might have traveled into the Zape or Ramous regions, bringing merchandise and looking for exploitable trade items. If a *pochteca* died during the trading trip, he would have been appropriately buried in that region, which is the premise on which DiPeso et al (1974), Frisbie (1978) and Reyman (1978) have based their *pochteca* burial descriptions. If all that is recovered archaeologically is a cranium; the problem is whether the cultural trait of a particular type of artificial cranial deformation could be proved to be sufficiently reliable to serve as an identifying characeristic, as in this case from the Zape region where there are no associated artifactural data.

DESCRIPTION OF THE CRANIUM

Prior to describing the physical attributes of the Zape region cranium, an important aspect of the specific type of artificial cranial deformation under consideration needs emphasis. This cultural trait is not a casual, but a long term, process that must be started in infancy with specific methods of application. Saul (1972:10) has incorporated a clear definition of the terms and devices used in forming a tabular type of cranial deformation.

> . . . a Tabular category produced by fronto-occipital compression between thin boards . . .Each category was further subdivided into Erect and Oblique varieties according to the inclination of the occipital area upon the Frankfort plane. In the Erect variety, pressure was confined to the upper portion of the occipital and adjacent portions of the parietalia (the lambdoid area) resulting in an essentially vertical orientation or occasionally an anterior inclination of the occipital . . .The Oblique variety was subjected to overall pressure on the occipital bone to such an extent that the entire occipital was flattened and tilted posterior-

ly. Although the orientation of the occipital bone has been used to differentiate between varieties, there is likely to be concurrent deformation (flattening) of the frontal bone in both the Erect and Oblique varieties, owing to the nature of the deforming apparatus.

The Zape region cranium is that of an adult male, possibly in his late thirties at time of death, to judge by the occlusal surface wear of his teeth, particularly the left upper third molar. The age estimate is further confirmed by beginning osteophytic growth on the centra of the cervical vertebrae. Both nasal bones appear to have to have been broken and rehealed premortem (Plate 3).

The skull is partially covered with dried integument, some hair is still present in the vault area, and dried ligmentous and other soft tissues are holding six of the cervical vertebrae in position. These consist of the atlas, axis and cervical vertebrae 3 through 6. The cranial vault and facial bones are intact, but the mandible is absent and a number of teeth are missing post-mortem, including all the anterior teeth. From the right lateral view (Plate 1), it almost appears as if the anterior portion of the mandible is still present, as the skin and soft tissues have retained their original shape. On the parietal, superior to the temporal line and just posterior to the coronal suture is a break, through the dried scalp tissue and into the bone (Plates 2 and 4). This broken area was probably the result of handling by the boys when they vandalized the mummified burials.

No anthropometric measurements were taken as the dried integument and other tissues cover large portions of the cranium, as is shown in the plates. X-rays were taken (Plate 4) to explore the possibility of any cranial anomalies. No anomalies were observed and only age-related traits such as beginning tooth loss, caries and, on the right side, alveolar resorption where the upper right first and third molars had been lost. Some alveolar prognathism occurs and can be seen in the left lateral photograph (Plate 2). In the frontal view (Plate 5) on the right there is visible a supra-orbital foramen, while on the left a supra-orbital notch. The nasal bridge is concavo-convex in profile, which may relate to the breaking of the nose during life. There is a slight amount of glabellar swelling, but little or no brow ridge development, perhaps a result of the fronto-occipital deformation.

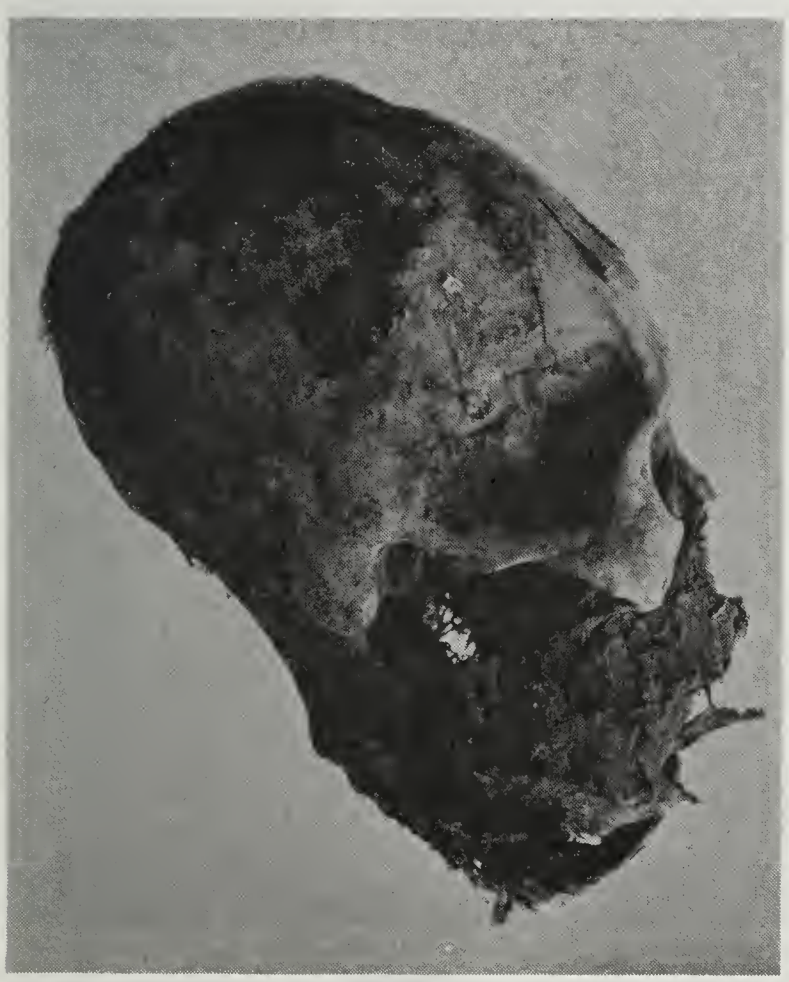


Plate 1

Plate 2

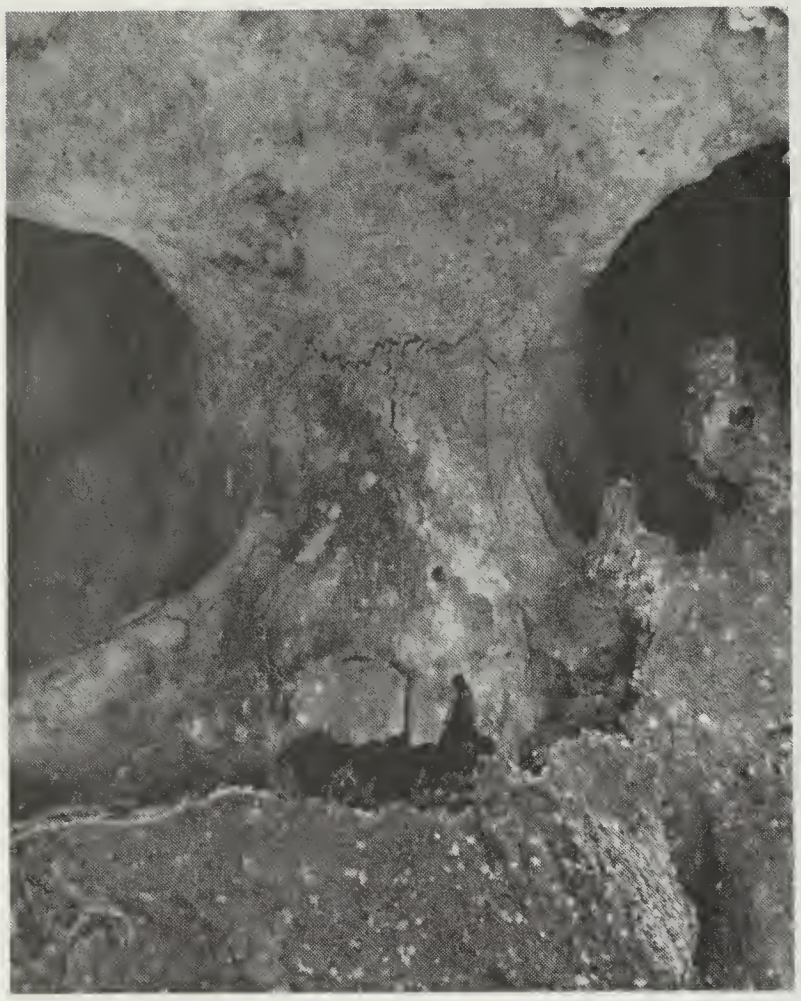


Plate 3

Plate 4

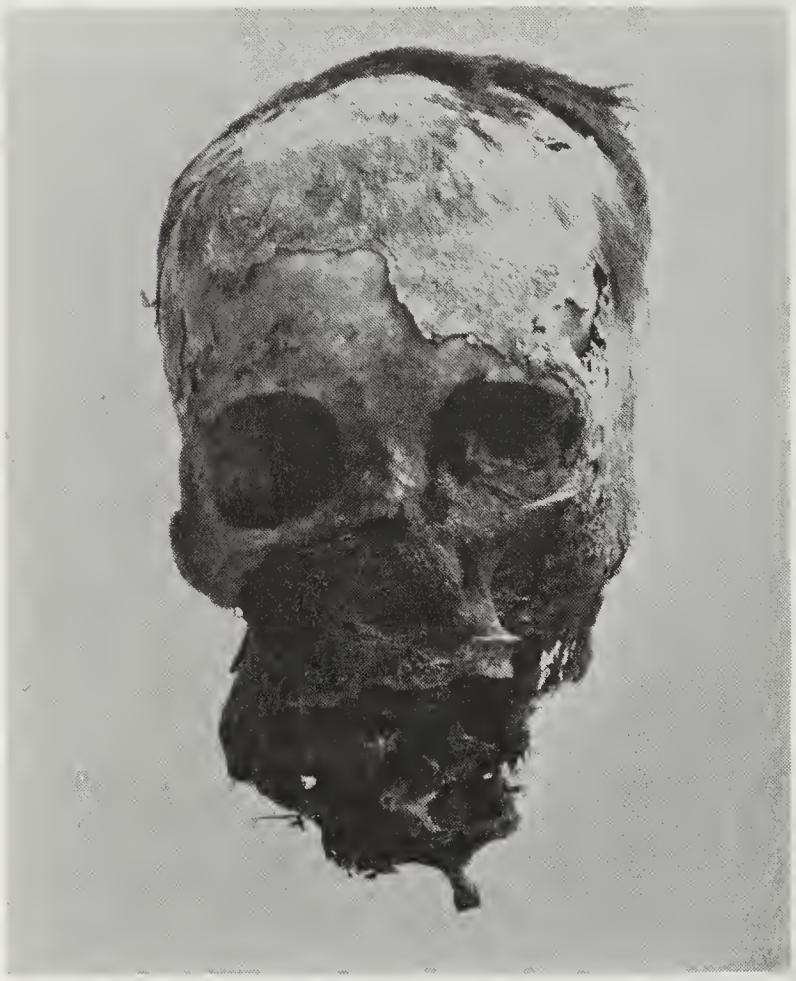


Plate 5

Plate 6

Plate 7

Plate 8

The nuchal area is covered with integument or ligamentous attachments, but there is development of a nuchal ridging that is apparent in the lateral x-ray (Plate 4). In the asterica portion of the left lambdoidal suture, where the bone is exposed, there are a number of wurmian bones, several of which are large. A few small wurmian bones occur in the left masto-occipital suture and one on the right at the parieto-mastoid section of the squamosal suture. Both right and left auditory meati are medium thick. the tabular oblique styly of cranial deformation has caused the pareital bosses to bulge prominently (Plate 6), with a slight depression at the sagittal suture. This is obscured in the photographs by the hair, but can be seen in direct observation.

DISCUSSION

During the Brooks' excavation of La Cueva de Los Muertos Chiquitos only crania of children or infants were encountered, although Delgado excavated at least one complete adult burial. The crania of the children exhibited bilateral occipital flattening, with concomitant enlarged parietal bosses, but no frontal flattening. A colleague, Raymond Rawson, through the cooperation of Arturo Romano, was able to photograph two skulls from the collections of the Museo Nacional in Mexico D.F. Both of these were identified as from an archaeological site in the Zape area. Plates 7 and 8 show lateral views demonstrating a similar cranial deformation to that exhibited by the children's crania from the small cave of Zape. The lack of flattening of the frontal area is most noticeable laterally. Comparison was made with the illustration of tabular erect cranial deformation (Romero, 1970:65), but both of the crania, photographed by Rawson, show rounder occipitals in addition to marked post-coronal depressions. The only way in which they resemble the Zape region cranium with tabular oblique deformation is in the enlargement of the parietal bosses as an effect of artificial deformation.

On the basis of the proposed prehistoric contact between the Zape region and the urban centers of the Chalchihuites culture in southern Durango, it was originally presumed that the tabular oblique deformed Zape region cranium might prove to have been the burial of a Chalchihuites individual. Robert Pickering, who is describing burials from Chalchihuites archaeological sites, wrote that ''in my notes, there is reference to the tabular erect form of cranial deformation and an erect bi-lobed form'' (1970), but as yet no comments on a tabular oblique type. For further comparison of skeletal data from sites within northwestern Mexico, east of the Sierra Madres, to obtain additional information on types of artificial cranial deformation common to the area, the Casas Grandes Reference Volume 8 (DiPeso et al, 1974) was consulted. Artifical cranial deformation was characteristic of

the burials from Casas Grandes, with symmetrical occipital deformation predominating. During the Viejo Period three individuals are described as exhibiting fronto-occipital deformation, two adult males, and a young adult female. ''This fronto-occipital deformation was of particular interest, because this custom, which did not prevail in the northern portion of the Gran Chichimeca, was practiced by some Mesoamericans'' (DiPeso et al, 1974:339). Unfortunately no illustration of the fronto-occipital deformation is included and from the description, it cannot be determined whether this was tabular oblique or tabular erect cranial deformation. There is a reference to three possible ''puchteca'' burials, one from the Diablo Phase and two from the Medio Period, but all three burials consisted only of post-cranial bones, with no associated crania (DiPeso et al, 1974:371).

Romero (1970) described several types of artificial cranial deformation, utilizing Dembo and Imbelloni's nomenclature for classification. He states that ''In any case, the predominant head deformation in Middle America was the tabular form in its two types, erect and oblique. Although both types are well represented throughout the whole pre-Spanish epoch, there is no doubt that the tabular oblique was much more frequent during the Late Classic period, especially within the Maya area'' (Romero, 1970:66). Certainly Saul's (1972) description of artificially deformed crania from the Altar de Sacrificios in the southwestern Peten confirms the predominance of tabular types of cranial deformation occurring in both male and female burials. Tentatively the ''Oblique variety of Tabular deformation seems to predominate in the Late Classic, while the Erect variety seems to be the primary form in the Postclassic . . .although both sexes are represented in all categories, more males are classified as Tabular Erect and more females as Tabular Oblique when time is held constant'' (Saul, 1972:17).

Present evidence from prehistoric sites in Mesoamerica supports the statement that ''head deformation had a very wide distribution in this area and dates from very remote time'' (Romero, 1970:65). In referring to this practice Romero is essentially discussing head deformation in the Nuclear Mesoamerican areas and according to his data ''tabular erect deformation is the most ancient in Middle America, having appeared in the cultural level corresponding to the Early Pre-classic (1400-1000 B.C.) in the Valley of Mexico; tabular oblique deformation was present also in the Valley of Mexico since the Late Preclassic (500-200 B.C.). In these two cultural levels both sexes exhibited deformation'' (Romero, 1970:66). These tabular types of cranial deformation occurred through to Aztec and late Mayan pre-contact times (Saul, 1972). There are other types of cranial deformation described by both Romero and Saul, but no mention of these alternate types is made by Pickering (1978) in referring to the Chalchihuites burial data, nor by DiPeso et al (1974) with reference to the burial sequences from Casas Grandes. Consequently if a specific type of cranial deformation might be selected as a physical trait to identify individuals, buried in Northwestern Mexico or the Greater Southwest, who derived from Nuclear Mesoamerica, tabular cranial deformation, oblique or erect, may be that trait. The people who would be traveling from Nuclear Mesoamerica into the outlying regions of northwestern Mexico and the Greater Southwest are most logically the *pochteca,* or merchant traders.

Certainly Dipeso et al (1974), Frisbie (1978), and Reyman (1978) support the strong probability of the physical presence in these regions of *pochteca* or trocadores on the bases of cultural and artifactual associations. DiPeso et al (1974:372) even speculate that ''the entire Mound of the Offerings complex suggested that three high-ranking individuals, perhaps the original *puchteca* patriarchal family, were given such ritual service.'' This description has reference to the three burials of the post-cranial skeletons of two males and a female in separate large ''Ramos Poly'' vessels. In his extensive review of high status burials in the Greater Southwest, including northwestern Mexico, Frisbie (1978) is concerned with the associated grave goods and bases his interpretation on these. He does refer occassionally to the stature of the high status individual, apparently where there is information available, but there is no description of the rest of the skeleton. His conclusion is that ''Casas Grandes and Chaco Canyon represent the northernmost sites in a long chain of centers connecting the northern frontier to the Valley of Mexico. Thus an approach

which favors the *pochteca* or *trocador* concept for the interpretation of status burials is, I believe, more congruent with the archaeological record than distinctions afforded by autonomous and egalitarian tribal organizations'' (Frisbie, 1978:227). If a particular type of cranial deformation were determined to be a trait characterizing the physical presence of a member of the *pochteca,* who had died while traveling and was buried appropriately, this factor would greatly strengthen Frisbie's *pochteca* model.

Although in Reyman's description of the *pochteca,* as derived from Mexican ethnohistorical and archaeological sources, there are listed numerous items as canes or staves, lip, ear and nose plugs, hair styles and facial makeup, there is no mention of cranial shape. He has data indicating that pochteca membership came from ''specific residential locales within Postclassic cities and towns'' (Reyman, 1978:244). From this statement it might be feasible to speculate that such individuals living in urban centers of Mesoamerica and from a high social status, in addition to having their lips, ears and noses modified to allow for Mesoamerican data infer that artificial cranial deformation was also an indication of high social status. Consequently the assumption is not illogical that *pochteca* members could be identified skeletally in burials outside of Nuclear Mesoamerica by artificial cranial deformation of a tabular type, either oblique or erect.

What appears to be needed now is specific research analyzing the crania from each of the high status burials described by both Frisbie and Reyman and a determination if there is artificial cranial deformation present and if so what type. There is the possibility that *pochteca* could have employed local people, ''incorporating them into their trade organization'' (Reyman, 1978:248), so that these individuals might demonstrate either no cranial deformation or a different type than has been discussed here. This aspect of the problem could perhaps involve additional osteological research utilizing discontinuous or discrete morphological trait analysis, which has aided in differentiating skeletal populations (Brooks et al, 1977). Reyman has suggested, for a specific burial, that ''a more thorough osteological examination is certainly in order to determine whether or not the individual falls within one of the generally recognized Southwestern physical 'types'; serological data, if they can still be obtained, might also be useful in this identification . . .'' (1978:258).

The archaeological implications of ongoing research, specifically oriented towards accumulating information on the distribution of types of cranial deformation in northwestern Mexico and the Greater Southwest, could have the intent of relating this data to the movements of *pochtecas* into the northwestern frontier along one of the possible trading corridors of the Sierra Madre Occidental. The inference would be that crania with a tabular type of cranial deformation, perhaps oblique or erect, are evidence of individual *pochteca* from Nuclear Mesoamerica. Additional osteological research utilizing methodologies that differentiate archaeologically recovered skeletal populations, even serology if possible, might then provide the substantiating evidence that Reyman called for to validate the presence of *pochteca* per se: ''a body warm or cold . . . a *pochteca* member in the flesh (or skeleton)'' (1978:243).

CONCLUSIONS

One aspect of archaeological writings has become apparent even in the limited research and readings related to the problems discussed in this paper. In the sources consulted there were frequent mentions of burials and of skeletons, but with the exception of Frisbie's commentary on stature, there is no physical or morphological description of the burial. Even in the Casas Grandes Reference Volume 8, where burials are discussed in some detail, there is only half a page (1974:334) describing the general morphology of the burials, and the exact type of cranial deformation is not clearly delineated. That fronto-occipital cranial deformation is noted for three individuals from Casas Grandes has been mentioned previously but this is hardly sufficient information, considering the significance that Romero and Saul attach to the various forms and types of cranial deformation and their potential for providing prehistoric cultural information.

That is not to say that physical anthropologists are not equally at fault. Both Romero (1970) and Saul (1972) discuss the difficulties of comparing the descriptive terminology used by physical anthropologists to delineate various types of artificial cranial deformation. Fortunately for this research, they both prefer the classification of Dembo and Imbelloni, which is based on the kind of pressures applied to the skull and the devices employed. Frequently it is necessary to compare an author's photographs with the cranium at hand to determine what type of deformation is being described. Uniform descriptive standards of classifying cranial deformation are needed (Saul, 1972) and should be agreed upon internationally. Only then can archaeologists and physical anthropologists understand precisely what they are talking about when delineating a particular style of artificial cranial deformation.

"The culturally controlled trait of cranial deformation" (Saul, 1972:28) could prove valuable to both archaeologists (as considered in this paper) and to physical anthropologists. "Varieties of artificial deformation may very well prove to be important indicators of population movements or at least of cultural diffusion . . .What is needed, of course, is . . .to evaluate and re-evaluate properly dated remains from many sites in middle America so that chronological flow charts might be prepared" (Saul, 1972:17). To Middle America there needs to be added the northwestern Mexico area, the Greater Southwest and perhaps other New World areas where the cultural trait of cranial deformation effectively has changed the biological patterns of the developing child's skull.

In a recent letter, David Browman (1978 has discussed a problem in Peru, similar to the one presented here concerning the presence of *pochteca* per se in northwestern Mexico and the Greater Southwest, and the possibility of artificial cranial deformation being the identifying trait.

> Briefly in Peru, we have unsolved questions on the relationship between two empires during the Middle Horizon (ca. A.D. 500-1000), the Wari and the Tiwanaku. Religion is obviously exported from Tiwanaku to the Wari, but we have trouble isolating other definite traits. My recent agrument has been:
>
> (a) High status burials in Tiwanaku have cranial deformation as early as A.D. 100.
>
> (b) Cranial deformation does not occur in the Wari areas with such burials until after A.D. 800.
>
> (c) There are however, some unique, in some cases two and three story, stone slab tombs at Wari, where the burials had cranial deformation (excavated unfortunately before we had any archaeologists in the area, decades ago). Reported goods indicate high status, and they are located in a part of the Wari capital city that some believe was a mercantile or market area.
>
> (d) Therefore I argued they were the merchant missionaries from Tiwanaku, or at least those trading with Tiwanaku, and that we might speculate on a variety of obvious correlations between cranial deformation, trade, and status.

With reference to Browman's proposal and Saul's concept of a chronological flow chart for Middle American cranial deformation, it is suggested that the flow chart be expanded to include South America, as well as North America. It should be considered whether there may be a common area from which both South American and Meaoamerican cranial deformation originated and from which this cultural trait diffused. The ideal aspect of utilizing artificial cranial deformation is that it is culturally controlled trait that can only be applied in early infancy and childhood by the adult generation. It directly affects the shape of the skull permanently and once the deformation is completed, it cannot be reversed. In effect there is created a culturally identifying impression on one aspect of the human skeleton that can always be recognized as long as the cranium is preserved. A clear delineation of the varieties of cranial deformation, in correlation with an accepted set of standards of classification, is essential. It will be necessary, as Saul suggests, to begin with well-dated burials and keep expanding the data base. After a distribution of types of cranial deformation has accumulated, centers where the highest frequencies of certain types of deformation occur can be plotted geographically and chronologically. The potential of this research is apparent for questions as those that are asked in this paper, or proposed by Browman for Peru, or as Saul has suggested for indicators of population movements.

In conclusion, a broadly based study of the distribution of the various forms of artificial cranial deformation in Mesoamerica, South America and North America has numerous ramifications for contributing to archaeological research in particular areas where alternate evidence is either lacking or insufficient. The problem of the actual presence of members of the *pochteca* in northwestern Mexico and the Greater Southwest might be resolved through knowing whether proposed *pochteca* burials evidenced cranial deformation. The diffusion of both cultural traits and population mobility could be traced chronologically through the analysis of dated burials with specific types od cranial deformation. There is also the possibility of establishing correlations between cranial deformation, trade and status, which not only has applicability to the situation in Peru, but also to that in Mesoamerica, and those areas of North America with which there was cultural contact, directly or through diffusion.

In closing we would like to express our thanks to Carry Stevens for assisting in photgraphic work and to Matthew McMakin for help with cartography.

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TRADE AND CONTACT IN THE PREHISTORIC SOUTHWEST

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ABSTRACT

Studies of diffusion and migration, whether interhemispheric or within a more localized area, have been mainly particularist in nature. There has been very little attention given to the development of either systematic methodologies or underlying basic theory.

In this paper, problems of methodology and theory are discussed in terms of Southwestern-Mesoamerican contact. Possible explanatory models for this interaction are considered, and one based on trade contacts is presented in some detail. The need for additional work is stressed.

TRADE AND CONTACT IN THE PREHISTORIC SOUTHWEST

The question of contacts between and among the disparate peoples whether interhemispheric or in more restricted areas has been of longterm interest—scholarly or otherwise. The intellectual conflict over pre-Columbian contacts between the Old World and the New World has a history of several centuries (see for example Lafaye 1976 for a recent discussion). Within the last century, influenced by the polarizing schools of unilinear evolution on the one hand and the various diffusionist schools on the other hand, the controversy has taken on a most vigorous life.

As we all know, this dispute has produced a great deal of heat and all too little light. The major reason for this, I believe, is that most of the discussion has revolved around particularist topics—generally the absense, presence, or likelihood of specific traits or complexes shared by the two hemispheres. Even such wide spectrum volumes as The Quest for America (Ashe et al, 1971) or Man across the Sea (Riley et al, 1971) have not unduly stressed methodological matters. In the latter volume, however, the editors did make certain suggestions for a coherent methodology, and presented a series of theoretical assumptions, some of which might be rephrased in terms of testable hypotheses while others were more or less in the nature of covering or nomethetic laws.

Since these were presented in a very tentative way, and people have not paid much attention to them, it might be worthwhile to restate them in terms of the use they may have to the problems specific to this paper. There were five points:

1. Man is a close-knit species in which all fully functioning adults participate at about the same level of culture.
2. Human beings universally react the same to various situations—the result of both cultural and biological heritage.
3. Man is inventive but the conformist and conservative nature of culture acts as a limiting factor in invention.
4. Invention demands some of the same kinds of psychological and cultural adaptations as diffusion. It is a kind of internal diffusion.
5. Additions to man's cultural inventory (whether invented or diffused) tend to be patterned.

There has, of course, been other attention given to the development of firm theory and method for diffusion studies. Robert L. Rands and I attempted some years ago to demonstrate that one could make general statements about the channelled nature of invention (Rands and Riley 1958). Recently Schneider (1977) has outlined what he calls a "genetic model" that tends to give theoretical underpinnings to diffusionist claims for widespread contact. Still and all, lack of attention to theory and method has been a great weakness in diffusion studies generally.

For the last few years I have been mainly interested in diffusion studies on a more restricted scale—the problems of Southwestern peoples and cultures and their relationship to the civilizations of Mesoamerica. My position in these studies has undergone change over the years. Beginning with the assumption that the development of Southwestern cultures was largely autonomous, I have come to believe, over the past two decades, that the Southwest is basically an extension of Mesoamerica.

In point of fact, the problems of Mesoamerican-Southwestern relationships are a microcosm of the problems of interhemispherical relationship and the approach has been much the same. In discussing contacts between Mesoamerica and the Southwest, experts, of whatever persuasion, tend to argue the case of specific events, trait distributions, artifactual finds, and to pay all too little attention to the underlying dynamics of cultural process that might allow working generalizations. As I indicated above, this is a basic problem when we deal with interhemispherical problems.

For a more theoretically oriented approach to Southwestern-Mesoamerican studies, we might logically expect help from the processual approach to archaeology, because of its strong hypothetical-deductive and model building proclivities. Unfortunately, a number of those Southwestern and Mesoamerican specialists who have been most affected by the "New" or processual archaeology have not—so far—shown any great interest in such problems as diffusion (see for example, Martin and Plog 1973). In the introduction to a recent book on Southwestern-Mesoamerican contacts, I make the point that:

> To date the "New Archaeology" . . .has contributed little to solving the problems of Mesoamerican-Southwestern connections. "New Archaeology" is primarily concerned with processual anthropology (usually defined as the interaction of cultural subsystems and of these systems with the natural environment). This approach tends to encourage internal explanation of cultural change, within arbitrarily defined universes. However, contacts, migrations, and diffusion in general also involve process . . . (Riley 1978a:7-8).

The desire to find internal explanations for the nature and direction of culture change is in itself a strong theoretical position drawn from neo-evolutionism and cultural ecology. There seems to be a tendency to disregard outside influences as being particularist events and of no value in explaining socio-cultural systems. This attitude can of course lead to a *reductio ad absurdum*. Inagine an anthropologist of the future explaining the human condition in southern California between A.D. 1500 and A.D. 2000 as the result of adaptive change by the various local Indian groups.

We may hope one day to have the sophistication to deal with controversial matters of diffusion and migration in terms perhaps of covering laws or at least of good-probability hypotheses. At present what we have in Southwestern studies is a problem in search of a theoretical base or at least of a firm methodology.

The opinions concerning the nature of Southwestern aboriginal culture vary from outright migrationism (Gladwin 1957) through strong and repeated contacts between Mesoamerica and the Southwest (Kelley and Kelley 1975, DiPeso 1968, Riley 1975, 1976, 1978b) to various degrees of treatment of the Southwest as autonomous. Curiously, when Southwestern studies were begun in the late 19th century the scholars of that time were nearly unanimous in a belief that the Southwest and Mesoamerica were intimately connected. Only after about 1910 with a rapid growth of Southwestern archaeology, ethnology, and ethohistory concentrating on the northern or American portion of the Southwest does the swing to theories of autonomy really get underway. At its extreme in the 1930s, serious and talented researchers were even ready to suggest that pottery itself had been independently invented in the northern part of the Southwest in spite of a virtually continuous distribution of ceramic producing groups from Colorado to the Andean region. Only maize, squash and beans were conceded as diffused items and they were thought to have moved into the area with little or no cultural baggage. It is almost as if the normal assumptions concerning the spread of culture did not operate for the upper Southwest. If one was to formulate a hypothesis to test this situation it might go something like this.

"The barriers between Mesoamerica and the Southwest are of such a nature that nothing of cultural significance can pass from one area to the other."

Underlying hypotheses might have to do with the structured nature of culture and parallelism of growth.

By the 1940s, however, this parellelism had become extraordinarily hard to accept. In the 1930s ethnological experts like E.C. Parsons had pointed out the striking similarities between Southwestern and various Mesoamerican cosmologies and of actual ceremonials including masked dances. The elaborate studies of men like J.W. Fewkes around the turn of the century on iconographic similarities between the pueblos and Mexico began to be revived, as well as the contact theories of scholars like A.F. Bandelier.

At first, Pueblo and Mesoamerican similarities especially in detail of ceremonial life were postulated to be post Spanish in origin (it was known that something like a thousand Mesoamerican Indians came with Coronado and many of them stayed in the Southwest). However, in the 1940s and 1950s archaeological details such as platforms and rows of columns at Chaco Canyon were identified and archaeologists began to rethink the implications of such pre-Columbian trade items as parrots and macaws, copper, pseudo-cloisonne pottery, and other southern materials. The stripping off and photographing of layer after layer of murals at the late prehistoric site of Kuaua and their publication by Bertha Dutton (1963) demonstrated the pre-Columbian date of Mesoamerican-like ceremonies.

Beginning in the late 1940s archaeologists like Isabel Kelly and Gordon Ekholm and in the 1950s still other scholars, including J. Charles Kelley, Charles C. DiPeso and R.L. Lister began large scale exploration especially of the much neglected lower portion of the Southwest. By the 1960s, as a result of work by these and other scholars, it could be demonstrated that cultures clearly Mesoamerican had penetrated deeply into the southern portions of the Southwest from at least the late Classic period. That there had been earlier contact from the south had already been demonstrated by finds of maize perhaps as early as 2000 B.C. in west Central New Mexico, and other early cultigens in adjacent northern Mexico. In the late 1960s and 1970s this work has continued, culminating in such large scale operations as Kelley's work at Alta Vista, DiPeso at Casas Grandes, and Lister and his associates at Chaco Canyon.

My own interest has been primarily focused on late prehistoric and early historic times. In that period there is rich documentation for trade and other contacts not only from the Southwest to Mesoamerica but also westward to the Pacific coast of California and eastward to the Mississippi River. Trade itself was widespread and deep and involved a variety of materials. This trade is farflung not only in space but in time; for example turquoise from the Cerrillos mines near Santa Fe (identified by neutron activation studies) shows up in central Zacatecas in the early A.D. centuries. Turquoise, again from Cerrillos, has been discovered in eastern Oklahoma in a site dating *c.* A.D. 1400 (Weigand personal communication). Exotic southern goods including parrots and parrot feathers were reaching Chaco Canyon by around A.D. 1030 (Kelley and Kelley 1975, 201-204), and Chaco also had stores of turquoise—tens of thousands of pieces. This and other evidence strongly suggests that the Chaco Canyon pueblos were functioning as suppliers in a trade network.

Turquoise, perhaps from central New Mexico, has been found in the Texarkana area, northern Mississippi, central Missouri, the Southern Colorado River area, and northern Sinaloa all on roughly the same time horizon, that is, *c.* A.D. 1400-1500. In this same late prehistoric period Olivella shells from coastal California reached central Kansas, and New Mexican pueblo pottery is found from eastern Texas to central Kansas and perhaps even Missouri. (Riley 1976, and 1978b and personal communication with R.T. Bray). In addition, Rio Grande glazed sherds dating around A.D. 1400 have been found in the Magdalena-Etzatlan area west of Guadalajara (Weigand 1976:3).

When the space and time implications of these trade centers are analyzed there seems to have been three major periods of contact. One of these is in the early A.D. centuries and corresponds to the rise of Anasazi Pueblo, Hohokam, and Mogollon to fully functioning macro-traditions. From

other evidence it seems clear that certain kinds of ceremonial structures and probably various religious elements came in at this time (Kelley 1966). A second wave of contacts corresponds to the rise of the Great Pueblo period in Chaco Canyon, the Sedentary Period in the Hohokam, the expansionist period at Casas Grandes, and, to some degree Classic Mimbres (LeBlanc 1976:5). This period is marked by a rich complex of Mesoamerican traits, differing from one sub area to another. There was, then, a "retreat" (that is, a lessening of Mesoamerican influences) dating from about A.D. 1130 to 1150 at Chaco Canyon to *c.* 1260 or later at Casa Grandes. This retreat may have related to the time of troubles in central Mexico that followed the collapse of the Toltec kingdom, and perhaps, specifically, the Tarascan interdiction of trade routes to the Mexican west and north.

A third time of intense interaction seems to have begun sometime between A.D. 1300 and 1400. By A.D. 1500 trade routes (through a series of middlemen) linked areas as distant as Sinaloa and Kansas; California and Texas. This situation was still in existence at the time of the first Spanish contact with the Southwest in the 1530s and continued to be reasonably well documented for the next half century. Aboriginal trade networks were finally disrupted by Spanish occupation of New Mexico around A.D. 1600 and Sinaloa-Sonora from the 1620s and 1630s (Riley 1976: 44-45; n.d.a, n.d.b).

What I have just outlined represents a chronological ordering of data and a series of historical inferences from these data. It is, however, possible to construct a model that has both diachronic and synchronic implications that fit these data. This model was not invented by me. Versions of it have been utilized in the past by DiPeso and J.C. Kelley, among others, and, indeed, certain elements were discussed as early as the late 19th century. To some extent it rests on the economic work of Karl Polanyi.

I suggest that the Greater Southwest, slowly picking up cultural baggage (e.g., techniques of maize agriculture) from the Mesoamerican heartland, but lagging behind that heartland in sophistication, became very early an area of exploitation by Mesoamericans. The process was initiated and encouraged by a strong demand for certain kinds of luxury, rare, and exotic materials in the Mesoamerican heartland and the development of trade networks and trading organizations to meet this demand. That such organizations *did* develop is a necessary hypothesis for this model and it can be tested in various ways. I do not wish to go into this kind of testing in this summary paper but—let me say—I think that it has been adequately demonstrated both for Mesoamerica itself and for the Southwest. For more general purposes the hypothesis should be phrased in broader terms—that civilized or surplus producing societies utilize some of that surplus for luxury or prestige goods obtained by trade.

Of course, alternative models for the Southwest, specifically, and for early civilizations, generally, that would fulfill the conditions of the hypothesis, are ones that involve political or religious conquest or both. Such alternative models are not, of course, mutually exclusive with the trade paradigm—for example we have clearcut evidence that Aztec traders (the Pochteca) were also agents of state military and political imperialism.

Since trade networks are sensitive to changing political situations one would expect a fluctuation on the frontier as conditions changed in the heartland. Indeed, as far as the Southwest is concerned this likely does happen, the ending of two great contact phases seeming in a broad way to relate to events at the ends of Classic and Post Classic times in Mesoamerica. The third contact period was ended by the Spaniards and the beheading of the Mesoamerican Great Tradition.

Another hypothesis (or perhaps a more fundamental nomothetic statement) that is crucial to this model involves the functional nature of human culture. Put in basic terms it states that introduction of one foreign element to a culture *must* bring in other elements. Trade networks, therefore, introduced significant religious, ceremonial, artistic, and technological changes into the Southwest. Some of these doubtlessly went beyond the Southwest for this large area, itself, became a kind of center with rather farflung trading ties to the east and west as well as the south (Kelley and Kelley 1975; Riley 1976, 1978b).

The period of intense trading activity brought a series of drastic political and religious innovations. DiPeso (1968: 45-61), sees the introduction of Quetzalcoatl, Tezcatlipoca, and Huitzilopochtl worship by successive waves of trade-oriented Mesoamericans.

In order to maximize the research effort on Mesoamerican-Southwestern contacts, regardless of whether this or another hypothetical model is used, it is necessary to utilize interactively the fields of archaeology, ethnohistory, and ethnology. The first allows us to trace actual trade goods from Mesoamerica to the Southwest and vice versa, gives information on the nature of these trade goods, and on regional specialization. Through the methodologies of processual archaeology we can investigate the social and political organization of various Southwestern peoples, their demographic situation, and their abilities to exploit their environment, etc. The ethnohistorical data are very important, indeed, for in the Spanish accounts of the period 1530-1600 we have documentation of the existence, nature, and intensity of the trade situation. Later ethnological studies, especially for the Pueblo Indians from whom we have very detailed reports, give us rich clues to the aboriginal situation, especially in terms of cosmology, religion, and ceremonial life.

Because of the large date base, and the relatively clear-cut nature of the contacts, we should be able to work out for Mesoamerica and for the Southwest at least a partly verifiable sequence of events. In a sense we can work backwards, not only testing hypotheses but also testing methodologies against known series of events. Those hypotheses and those methodologies that are developed for the Southwestern-Mesoamerican contact situation can be analyzed for wider application. The Mesoamerican-Southwestern studies might then become a microcosmic testing ground for larger, interhemispheric problems.

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THE UPPER RIO SONORA VALLEY IN PREHISTORIC TRADE

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ABSTRACT

Results of recent archaeological research in the upper Rio Sonora valley are discussed, presenting data on local settlement-subsistence patterns, non-subsistence patterns, non-subsistence agriculture and related activities, community architecture, including the presence of possible ball courts, and the existence of a ranked society in northeastern Sonora in late prehistoric times. A network of external trade, dominated by economic relations with Casas Grandes, is postulated.

THE UPPER RIO SONORA VALLEY IN PREHISTORIC TRADE

This paper is based on a project being conducted at this writing in northeastern Sonora, Mexico, by the University of Oklahoma.[1] One of the primary goals of the project is the identification of trade routes and the nature of trade systems that were active between Mesoamerica and the classic Southwest, i.e., the Southwest north of the international border.

In the current debate in archaeological theory and method, I find myself in general agreement with logical-positivism and a theoretical framework based on the principles of general systems theory. In addition, I prefer the hypothetico-deductive method as a means of testing inferences whenever possible and/or practical (Tuggle, Townsend, & Riley, 1972; Hil, 1972; Watson, LeBlanc, & Redman, 1971).

The value of this approach has been demonstrated in a number of studies (e.g., Flannery & Coe, 1968, 1970, 1972; Longacre, 1968; Struever, 1968; Thomas, 1973). The systems theorists view human populations as components of ecological systems, doing away with the artificial boundary between culture and nature. Systems are understood in terms of the relationships between the components. Hence human behavior is the expression of part of the relationship between the human component and the rest of the system. It is only a part of the relationship, since the system is characterized by feedback, which in turn affects the human component.

While retaining the notion that human behavior is patterned, systems theorists reject the concept of culture as a set of shared ideas. The latter concept implies that all members of a given society share equally in the set of ideas that define the culture, whereas it is recognized that different persons exhibit different behaviors in different situations, and not everyone participates in all activities. Thus, culture is a shorthand notion for the sum of activities, but the latter represent relationships within sub-systems which overlap in the human component.

While subscribing to this theoretical approach, I am nevertheless in disagreement with many of its adherents in terms of its application, at least insofar as Southwest is concerned.

In past years Southwestern archaeologists have tended to treat the Southwest in isolation, looking to external Mesoamerican sources only for the initial introduction of a few basic traits such as maize and pottery. A number of explanations for this phenomenon have been offered. Taylor (1954:566) has suggested that Kidder was greatly influenced by the culture area concept and in turn influenced the subsequent direction of Southwestern archaeology along geographic, or areal, lines. Rouse (1954:573), commenting on Taylor's thesis, suggests an alternative, that Southwesternists were more influenced by the concept of traditon, tracing the spatial-temporal histories of archaeologically defined culture units such as the San Juan Anasazi or Hohokam.

I suspect both Taylor and Rouse are correct. Certainly a rather limited notion of the geographic Southwest conditions the thinking of most scholars considering themselves Southwesternists. A

review of the literature reveals numerous discussions concerning the relationships between Mesa Verde and Chaco Canyon; the Sinaqua, Salado, and Hohokam; and the various branches of the Mogollon. Yet in a recent, mis-titled synthesis of Southwestern prehistory the great site of Casas Grandes is not even mentioned, although a mere 65 miles south of the border (Martin & Plog, 1973). Indeed, maps of the Southwest presented in a number of such syntheses reveal a remarkable historical coincidence, namely that the southern border of the Gadsden Purchase exactly corresponds to an anthropologically defined prehistoric culture area (e.g., McGregor, 1965; Martin & Plog, 1973).

At the same time, the nature of southwestern antiquities, the elaborate ceramic typologies, the architecture, the availability of dendrochronology, the excellent preservation of perishable materials, and the evident continuity of prehistoric cultures with historic pueblos, all conspire to make it relatively easy to construct local developmental sequences. The latter in turn make it appear unnecessary to look beyond the local area for explanation, since each phase seems to have its antecedents in immediately preceding phases. When such was not the case, there was always the thought that many portions of the Southwest were yet to be explored and held the missing data.

It must be remembered that when the above trends in Southwestern research were developing, Mesoamerican archaeology was also in its infancy some 1000 miles away, with unknown territory lying between. It is not surprising that for an archaeologist excavating a seemingly perfect sequence from primitive Basketmaker to classic Pueblo, the Valley of Mexico seemed remote and irrelevant.

Whatever the reasons, the fact remains that Southwesternists from early 1920s until recently have devoted themselves to "filling in the gaps," as Taylor put it, within the Southwest north of the border.

There have been a few notable exceptions to the above. In 1932 Beals published his concept of the "Greater Southwest," which added all of northwest Mexico to the Southwest culture area. Haury (1945) discussed diffusion corridors through northwest Mexico, while Ferdon (1955) noted architectural parallels between Mesoamerica and the Southwest, postulating direct Mesoamerican intervention as an explanation.

More recently such scholars as Kelley (e.g., 1966, 1975), DiPeso (1974), Haury (1976), and Weigand, et al (1977) have argued persuasively for the view that the Southwest was heavily influenced by Mesoamerica, some even suggesting the actual presence of Mesoamericans as far north as Chaco Canyon. DiPeso has made a strong case for the interpretation of Casas Grandes as a Mesoamerican trading center, with links across the sierras and southward to the Mesoamerican frontier in Sinaloa.

The period when these recent developments in the study of Southwest-Mesoamerican interaction were coming about happened to coincide with the very time when a number of young, and not so young, innovative archaeologists were introducing to the field their notions of logical positivism, general systems theory, and the hypothetico-deductive method, with the lofty claim that their approach had the power of finally converting archaeology from culture history to science. Their persuasive, and often polemic, arguments for this point of view are characterized by an emphasis on clearly stated premises and the rigorous testing of propositions. It is therefore surprising to find the Southwestern practitioners among them continuing to follow the isolationist tradition of their predecessors in the face of the abundant evidence which has been compiled and reported on Southwest-Mesoamerican interaction.

It is here that I begin to find myself in disagreement. Since my research strategy is founded on the same body of general systems theory and methods of testing, it is relevant to examine how it is that the goals of my Sonoran research can be so far removed from the interpretations of the Southwest offered by others using ostensibly the same theoretical approach.

Martin and Plog's (1973) comprehensive study of the "Southwest" will be used as a foil since it represents an attempt at synthesis based on the theories discussed here; it represents the neo-

isolationism noted above; and because the authors felt compelled to devote a chapter to the explicit denial of external influences as relevant to an understanding of the Southwest.

Hall and Fagen describe a hierarchical order of systems, such that any system can be divided into subsystems and any system is itself a subsystem of a larger system (1968:83-84). In effect, in order to deal with phenomena systemically, we must first identify the system, and the very act of doing so is synonymous with placing artificial boundaries around a subsystem of a larger system. The environment of a system is defined by Hall and Fagen as "the set of all objects a change in whose attributes affect the system and also those objects whose attributes are changed by the behavior system" (Ibid:83). Hence, when we bound a subsystem, the larger system becomes the environment by definition.

It should be obvious that interaction takes place between subsystems and the larger system, as well as between subsystems. This is because the larger system, and all its remaining subsystem components, are part of the environment of the system in question. However, when dealing with a given system, we need not necessarily be concerned with the nature of the larger system of which it is a part, but only with the inputs from the larger system, as well as the outputs from the system in question. If we define a light switch, wires, and ceiling light as a system, we need not concern ourselves with the power plant generating the requisite energy or the system of transmission lines, but only with the input of energy through the switch. However, this cannot be stated as an absolute rule. In some cases we may well need to consider the nature of the larger system in order to understand the inputs for the system in question.

In reference to interaction between local groups, Martin and Plog (1973:331) make the observation that "human cultural systems are not closed; substantial quantities of matter, energy, and information cross their boundaries. To the extent that these flows are significant between two systems, events in one will affect events in the other."

Such a statement is in complete agreement with the preceding description of system relationships. It should be noted, however, that Martin & Plog make this observation in reference to relationships between communities in marginal and nonmarginal areas within the Southwest. When it comes to inputs from beyond their borders of the Southwest, i.e., Mesoamerican inputs, they drop their systemic model entirely and argue in terms of diffusion and migration, citing Harris' contention that diffusion explains nothing. Implicit here is the non-stated premise that inter-cultural relationships within the Southwest are systemic while similar relationships extending beyond the Southwest are non-systemic. Hence we are told that relationships with Mexico are of little concern because they are "of historical more than explanatory interest" (Ibid:345).

I suspect that the failure of system theorists in the Southwest to recognize the relevance of Mesoamerica to their research is a function of the units of analysis they define, such as Hohokam, Anasazi, and Mogollon, or smaller geographic entities such as Chaco Canyon and Mesa Verde. The latter may well be derived from the old expeditionary attitude described by Taylor (1954). But given their apparent understanding of systems theory, how is it possible for Martin and Plog to discuss cogently the interaction between local groups (systems) and yet fail to recognize the obvious extension of such a model to larger systems? The answer, I believe, is revealed in the following passage:

> Certainly we may be able to learn a bit about historical development in Arizona by studying diffusion, but as a concept or a model for studying sociocultural changes or for searching for regularities, for questions concerning casusality and origins, or *for applying the principle of technoenvironmental determinism,* it is inadequate precisely because one cannot test its implications for explanation and prediction (1973:339-340; italics mine).

While generally claiming an affinity with anthropology, with all its goals and aims, most archaeologists using systems theory argue in terms of explaining prehistoric phenomena. I see this as particularistic, whereas anthropology is said to be a generalizing science. While it is perfectly legitimate to have an historical interest in prehistory, as anthropologists our concern with

prehistory is as a data source for generating and testing models of explantion as opposed to applying such models. Thomas exemplifies this point of view in his test of Steward's model of Great Basin settlement patterns (1973).

Leaving aside the incredible statement that the implications of diffusion cannot be tested, Martin and Plog in the above passage expose their concern with explaining the prehistory of the Southwest by application of the principle of technoenvironmental determinism.

The application of the hypothetico-deductive method, as correctly noted by Binford (1968), Hill (1972), and others, calls for the testing of numerous, contrasting propositions, not just one. Southwestern proponents of this approach are often guilty of violating this tenet. Martin and Plog are specific examples, explicitly subscribing to the explanatory devise labelled technoenvironmental determinism. They do not set forth this concept to be tested against the data of prehistory, but rather apply it as it a given. Furthermore, implicit in their interpretation of the Southwest data is a restriction on the concept. There is no inherent contradiction between technoenvironmental determinism and the notion of world systems. Their rejection of external factors as having no significant influence on the development of Southwestern cultures, in spite of abundant evidence to the contrary, clearly implies that what they really mean is *local* technoenvironmental determinism. Unfortunately, since they are apparently unaware of this unstated premise, they also fail to define its geographic and/or socio-cultural limits. In other words, how local is local?

Because of their hidden premise noted above and the fact that they are simply applying the principle as a given, Martin and Plog are able to reject out of hand all data pertaining to external inputs as irrelevant. From their premise such rejection logically follows, and they cannot be faulted for that. However, had they been concerned with setting forth their premise as a proposition to be tested, and hence followed through with the testing of alternative propositions, they would have been forced to consider the Mesoamerican data. Instead, while explicitly recognizing relationships between cultural systems within the Southwest, they fail to recognize that interaction between these systems and Mesoamerica represents the same kind of phenomena. Our proposal of a Mesoamerican world system, adapted from Wallerstein (1974; Pailes & Whitecotton, 1975), and our subsequent research in Sonora, is an attempt to remedy this situation.

Based on an analysis of the rise of European world economic dominance beginning in the sixteenth century, Wallerstein has proposed a model of world economics which describes the systemic relationship between the various components of what he calls a world system. He defines four components: the core, semiperiphery, periphery, and external arena. The first three together make up a system which is integrated economically but does not have political autonomy. Each of the three components is distinctive, and each serves specific functions necessary for the operation and maintenance of the system as a whole. Both political and economic power are unequally distributed among the three components, with the core area being dominant. In addition, the three components are themselves subdivided into a number of socio-cultural units. Hence the core area does not represent a single polity, but a number of economically and politically competing states. The external arena consists of those socio-cultural units which are outside the system, although in contact with it. An important point here is that, because the external arena is by definition not a part of the system in question, it is unaffected by it. Contact between the external arena and the system is sporadic, brief, and characterized by the acquisition of windfall profits on both sides.

Following Wallerstein's model, a Mesoamerican world system has been suggested with the Southwest as a peripheral area (Pailes & Whitecotton, 1975). One of the long range objectives of our Sonoran research has been to test this model archaeologically.

Evidence for intermittently intensive, but continuous, contact between Mesoamerica and the Southwest has been abundantly provided in a number of references previously cited. One problem has always been to identify the actual mechanism for all of this Mesoamerican-Southwest interaction. The most frequent response has been to invoke Pochteca-like trading groups as the guilty parties responsible for contaminating our pristine Southwestern sites with Mesoamerican stuff. This

has the happy advantage of allowing us to leap a thousand miles in a single bound without worrying too much about all that archaeologically unknown territory in between.

The project discussed here was in part designed to try to understand more about the actual mechanisms of interaction that were taking place in pre-Spanish times. The continued uncovering of Mesoamerican traits and/or trade items within the Southwest itself, while serving to reinforce our conclusion that the Southwest was indeed a peripheral area in a larger world system, does not alone define the nature of the system. By examining the intervening areas we hope to uncover evidence that will at least allow us to identify the kind of trade systems that were active.

We chose eastern Sonora because:

(1) It was one of those unknown intervening areas, a virtual blank on the archaeological map.

(2) The author had previously found evidence for the existence of a more or less common cultural tradition extending the entire north-south length of eastern Sonora and northwestern Chihuahua, from Casas Grandes all the way into northern Sinaloa, where it was in direct contact with Mesoamerican culture on the west coast (Pailes, 1972, 1976).

(3) The area just happens to straddle the best north-south routes of travel on the west side of the sierras.

If the eastern Sonora foothill zone did serve as an ongoing diffusion corridor between Mesoamerica and the Southwest, evidence should be found in the Rio Sonora culture sites in the form of specific trade items and locally made items not directly related to subsistence requirements, but derived from Mesoamerican and Southwestern sources. Such a proposition is relatively easy to test, and our data have already done so.

The abundance of trade pottery from Casas Grandes province indicates that trade into or through eastern Sonora was extensive, while marine shell from the coast and various Mesoamerican items such as copper crotals, Guasave Red pottery, a number of typologically unidentified sherds of west Mexican origin, and effigy vessels indicate interaction with peoples to the west and south. Determining the nature of such interaction is more difficult.

Following DiPeso, we postulated that Casas Grandes was a northern terminus for a trade route which passed through eastern Sonora. Our concern has been with determining whether the exchange system was based on a group of long distance traders comparable to the *pochteca,* or based on a system of numerous, overlapping local trade networks, or both.

Two approaches are being used. In the first, we constructed a simple typology of trade systems, consisting of four types each characterized by a different means of trade goods transmission and different concomittant social relations (Pailes, 1978).

Type one consists of a series of overlapping local trade networks which were socially egalitarian, i.e. anyone who had a mind to could engage in trade. Type two also consists of a series of overlapping trade networks, but contrasted with the first type in that locally the system was characterized by social stratification, with the exchange of trade goods controlled by the elite.

Type three is characterized by long distance traders who, alone, travelled between distant points. The difference between this type and the next lies in the origin and cultural background to the traders. In this case, they would be natives of the Southwest, peripheral to Mesoamerica. The fourth type also features long distance trade, but characterized by traders from Mesoamerica, specializing in trade with distant peoples. The well know Aztec *pochteca* serves as a model here.

It is postulated that each of the above types of economic exchange would result in distinctive spatial distributions of trade goods relative to community and settlement patterns. Undoubtedly the actual situation was more complicated than the four types suggest. For one thing, there is no logical reason why more than one type could not have been operative at the same time. Even types one and two are not necessarily mutually exclusive, since each could involve different sets of trade goods. Nevertheless, we have attempted to predict trade goods distributions based on the above types for comparison with the actual situation as we find it.

The second approach to this problem again involves settlement pattern data. Using all of our

data on site size, site content, population estimates per site and for the valley as a whole, and environmental variables, but specifically excluding the settlement pattern, we are attempting to construct an expected settlement pattern model. This we are then comparing with the actual settlement pattern as we find it. Since the expected pattern is based entirely on internal factors, if it is at all accurate then anomalies in the actual pattern should be the result of external factors. The nature of the anomalies will then be used in conjunction with our first test of the four types of exchange.

Since the project is far from completion, it is too early to present conclusions. Nevertheless, some patterns are beginning to emerge. In the remainder of this paper I will briefly describe some of these data and their possible implications.

The area of research is in northeastern Sonora, taking in drainages of the upper Rio Sonora, Rio Fronteras, Rio Moctezuma, and Rio Sahuaripa (Fig. 1). These valleys all lie in what we have termed the eastern foothill zone of Sonora, above the 15 inch isohyet for mean annual rainfall. The rivers are all live streams, although some, such as the Rio Moctezuma, have alternate live and dry sections. This is in contrast to the rivers to the west, which are ephemeral, flowing intermittently only during the rainy season in summer. In addition, the foothill streams are all oriented on a north-south axis, and together with the Rio Cedros and Arroyo Cuchujaqui in southern Sonora, they form a north-south corridor from northern Sinaloa to the international border. The area can be considered a transition zone or ecotone between the Sierra Madre Occidental on the east and the Sonoran Desert on the west.

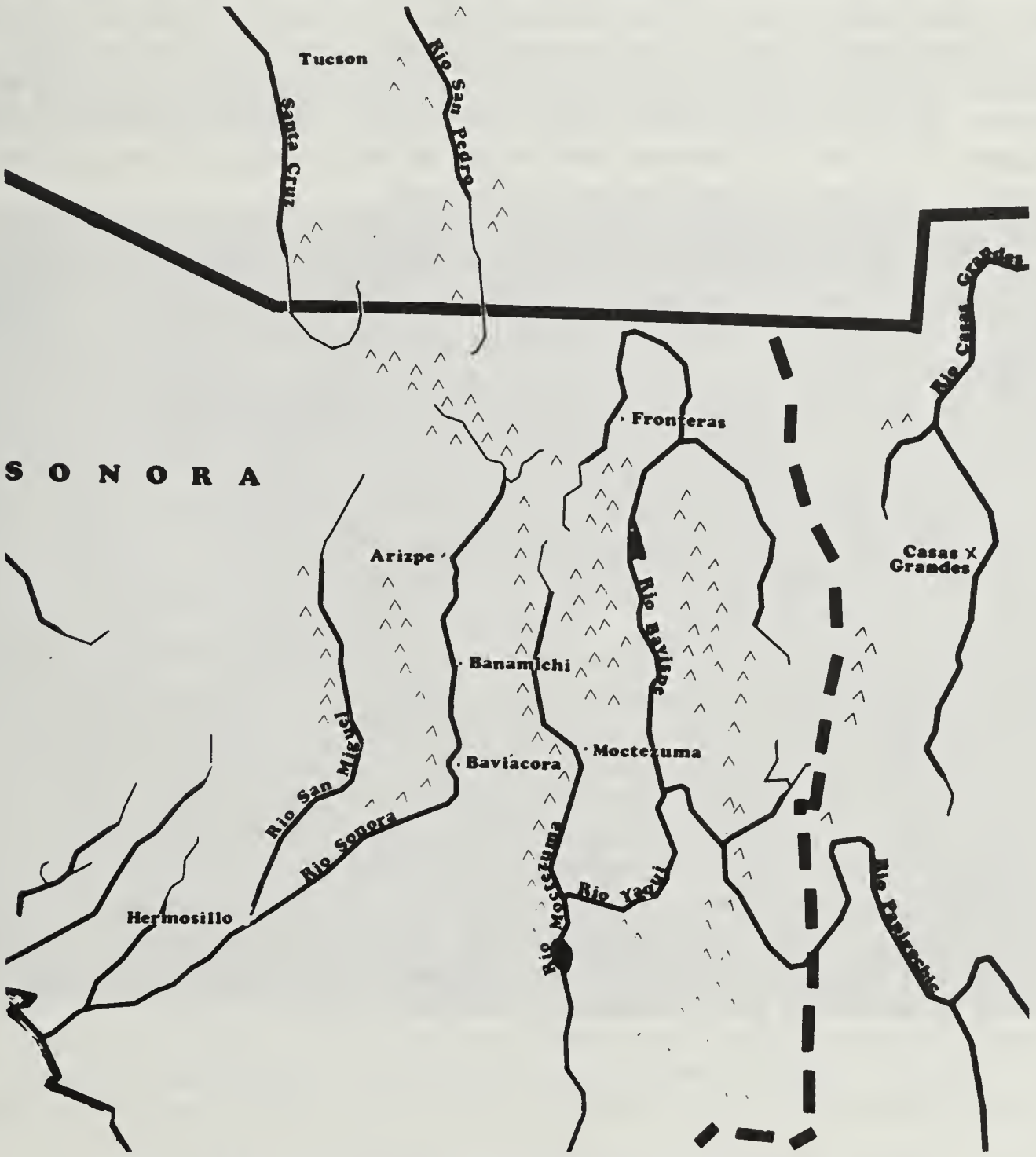

Fig. 1. Map of northeastern Sonora, showing the research area.

Our research efforts have been concentrated in the upper Rio Sonora valley, with some survey and test excavations in the remaining valleys both to obtain comparative date and to check some of our interpretations. The Rio Sonora valley can be divided into a number of more or less naturally defined segments characterized by a broadening of the floodplain. Two of these segments we call the Baviácora-Aconchi and Huepac-Banamichi segments after the principle towns in them.

The initial field season was devoted to site survey throughout the area, but with a concentration on the Rio Sonora valley. An intensive survey was conducted in the southern half of the Baviácora-Aconchi segment, with an effort made to locate every site. The data gathered was then used as a basis for conducting a more general survey throughout the remainder of the research area. In succeeding seasons the site survey was assigned to an advanced graduate student in geography having experience with archaeology, and the survey was continued concurrent with excavations. We now have as complete an inventory of sites as we can hope to obtain for the Baviácora-Aconchi and Huepac-Banamichi segments of the valley, and less complete surveys north of Banamichi as far as Arizpe and south of Banamichi as far as Molinote some twenty kilometers away.

To date we have recorded 279 sites, with controlled collections from roughly two thirds of them. The remaining one third were of such a nature that controlled collecting procedures would have been impractical for a variety of reasons. In the upper Rio Sonora valley, where our research has been concentrated, a total of 253 sites have been surveyed.

In the combined Baviácora-Aconchi and Huepac-Banamichi segments of the valley we have 227 prehistoric or very early historic sites. Of these, 162 appear to have been permanent habitation settlements which are consistently found on the edge of the lower bajada overlooking the river floodplain or large tributary arroyos. The remaining 65 sites consist of check dam sites, isolated clusters of roasting pits or debris scatters probably representing seasonal activity sites.

The project geographer has developed some tentative interpretations concerning the settlement pattern in these two segments of the valley which seem to check out positively in other parts of the research area. The 162 habitation settlements fall into three groups, based on size, house number, and the presence of special architectural features.

Three sites dominate the pattern by their size, having 85 or more structures, the largest having in excess of 125 observable structures. One of these, the San José site, is centrally located in the Baviácora-Aconchi segment of the valley. The Huepac-Banamichi segment is twice as large, and is dominated by two large sites, the Las Delicias del Sur site in the northern half and the Ojo de Agua site in the southern half.

There are only two intermediate size sites. One is located on the west side of the river floodplain at the north end of the Huepac-Banamichi segment. Its size seems to be a function of local topography. The second is the La Mora site, which is located on the edge of the lower bajada central to the Huepac-Banamichi valley segment, midway between the two large sites. It is unique due both to its intermediate size and to the presence of public architecture.

The remaining 157 habitation sites are all small, having fewer than 20 structures, with 100 having fewer than five structures.

Finally, the large San José site in the Baviácora-Aconchi segment and the intermediate sized La Mora site in the Huepac—Banamichi segment have large public structures consisting each of two elongate parallel platforms with plaze-like areas between them. At the San Jose site the two platforms are connected at their ends by crosswalls to form a rectangular interior court or plaza (Fig. 2). The interior dimensions are twenty-four meters from platform to platform and forty-six meters from end wall to end wall. The platforms, and hence the long axis of the entire structure, are oriented a few degrees west of north, paralleling the edge of the mesa.

The east platform is approximately one meter high in its present condition, and two and a half meters across (Fig. 3). At the southeast corner of the structure, the east platform extends some ten meters beyond the south crosswall, its entire length being some fifty-six meters. Its exact length cannot be determined due to vandalism at the south end.

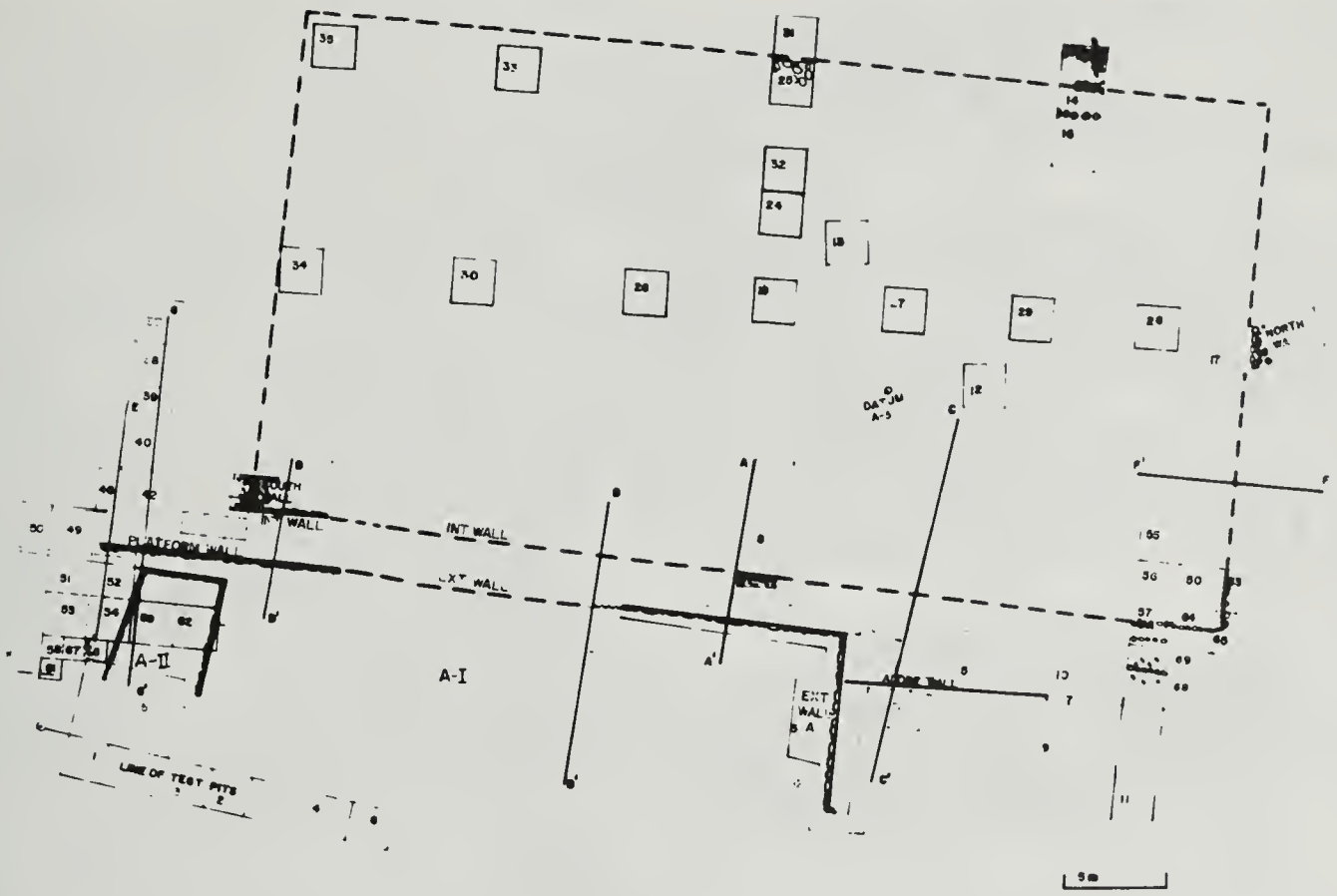

Fig. 2. Structure A-I, the court-platform structure at the San José site. Dash line indicates outline of structure. Small circles indicate rocks. Fine solid lines indicate excavation areas.

Fig. 3. East platform, looking south on top of the platform. On the left can be seen the exterior edge of the platform after excavation. On the right a trench extends against the interior wall. In the background on the right can be seen the sloping talus from the platform before excavation.

Fig. 4. Interior wall of court-platform structure at San José.

The platform was constructed by building three parallel stone walls and filling the space between the two most distant with rocks and trash. As a result, the middle wall was buried within the platform. The interior wall, i.e., facing the interior court, was crudely constructed of boulders, but may well have been finished with adobe plaster that has since melted away (Fig. 4). The middle wall, buried within the platform, consisted of a linear pile of boulders noticeably larger than the other rocks making up the general fill of the platform.

The exterior wall, i.e., on the east face of the platform was faced with flattish rocks placed on edge for the southern two thirds of its length. At this point a wing wall was constructed extending eastward from the platform. The slab facing along the east wall of the platform continued along the wing wall, while the remainder of the platform north of the wing wall had an exterior finish similar in construction to the interior wall. A plaza-like area appears to have been present adjoining the platform on the east and south of the wing wall. At present this area is noticeably level and lacks architectural features of any kind.

The west platform was built along the edge of the mesa where its position facilitated its more rapid erosion. Hence, in its present condition it is not as high or clearly identifiable as is the east platform. Two trenches sectioning the west platform confirm that it was constructed in a manner similar to the east platform, but lacked the slab facing on its exterior side.

The end walls on the south and north were of simple boulder construction, approximately one-half meter wide.

At its south end, the extension of the east platform was constructed over the ruin of a former rectangular surface structure, and evidence suggests that the latter was deliberately razed to make way for the platform construction. Finally, near the south end of the east platform was a small, U-shaped surface structure opening to the east.

At the La Mora site, more or less centrally located in the Huepac-Banamichi segment, was found another structure similar to the court-platform structure at San José. Since this structure has not been excavated, dimensions are approximate. The interior court is some twenty-five meters wide from platform to platform. However, the platforms extend only about two-thirds the length of the long axis of the court. The remaining one third is bordered by rock alignments representing a continuation of the exterior walls of the platforms, so that the court area is in the shape of a T. In place of the end walls found with the court-platform structure at San José, the La Mora structure has the foundations of two rectangular surface structures, one at each end. The distance between structures, and hence the length of the interior court, is forty-five meters.

The settlement pattern data tend to indicate that there was no central place hierarchy within each of the valley segments, but that the large sites served all other sites with no intermediate sites functioning as secondary centers. On the other hand, the La Mora site suggests that whatever economic and/or political functions were served by the dominant sites, they were apparently distinct from the functions served by the court-platform complexes, at least in the Huepac-Banamichi segment.

Thirty-four sites have been partially excavated in the course of the project, providing data from 59 structures and numerous test pits. A part of two seasons were devoted to the San José site because of its obvious importance. The site is approximately .25 km² (61.75 acres) in size and has in excess of 100 structures visible on the surface in addition to the court-platform structure noted above.

At this point we are able to identify tentatively at least four occupational phases at the San José site, based on the architectural sequence. The earliest two phases are characterized by houses in pits, and can be distinguished from each other by certain details in one of the houses. This was a house in a pit, approximately eight and a half by five meters, and about 90 centimeters in depth. Significant attributes for identification of the early phase are the presence of a plastered, sloping entry on the west and a plastered floor (Figs. 5 and 6). The house was destroyed by fire, and produced two radiocarbon dates of 1075 and 1085 A.D. Subsequently, the same structure was rebuilt, but on a different model. A regular pattern of 72 postholes in the floor indicate a raised floor, and a new entry was constructed on the east side of the structure, flanked by two massive blocks of adobe (Fig. 7). At least three other pithouses have been found with these features, and are indicative of a second phase. The structure burned a second time and provided radiocarbon dates of 1305 and 1315 A.D.

A third phase is represented by rectangular surface structures of adobe construction with stone imbedded foundations. We have at least one clear case of superposition, in which such a surface structure overlies a house in a pit of the most recent type (Figs. 8, 9, and 10). However, I suspect that the late type houses-in-a-pit are actually contemporaneous with the surface structures.

Finally, we have the large public structure at the San José site, overlying a rectangular structure of adobe construction. Presumably, some of the surface structures were contemporaneous with the public structure, but at least some must have been earlier.

A fifth phase for which we have evidence may represent a cultural tradition separate from the Rio Sonora culture. In addition, its chronologic placement is still uncertain. Four sites of this phase are characterized by crude stone wall enclosures on the highest hills, frequently in malpais, overlooking the Huepac-Banamichi segment of the floodplain. In at least one instance, cleared areas in the malpais suggest the presence of living areas surrounding the stone enclosure, although excavation produced no evidence of structures. The sites are suggestive of stone enclosures described for the Trincheras culture to the west, and it is probably significant that they are located in a segment of the valley near two passes that cross the mountains to the Rio San Miguel.

Finally, four unusual sites which cannot be placed chronologically or culturally suggest an intravalley pyral signal system comparable to the signal system reported by DiPeso to have been present in the Casas Grandes province. Each of these sites consists of a single, low, circular structure

Fig. 5. Entry of house-in-pit, San José site.

Fig. 6. Close-up of entry shown in fig. 5, showing mud plaster *in situ.*

Fig. 7. House-in-pit entry with massive adobe blocks. The edge of the house pit is in the foreground.

Fig. 8. Wall of surface structure overlying the entry of a house-in-pit. The adobe blocks of the house-in-pit. The adobe blocks of the house-in-pit entry can be seen on each side of the surface structure wall.

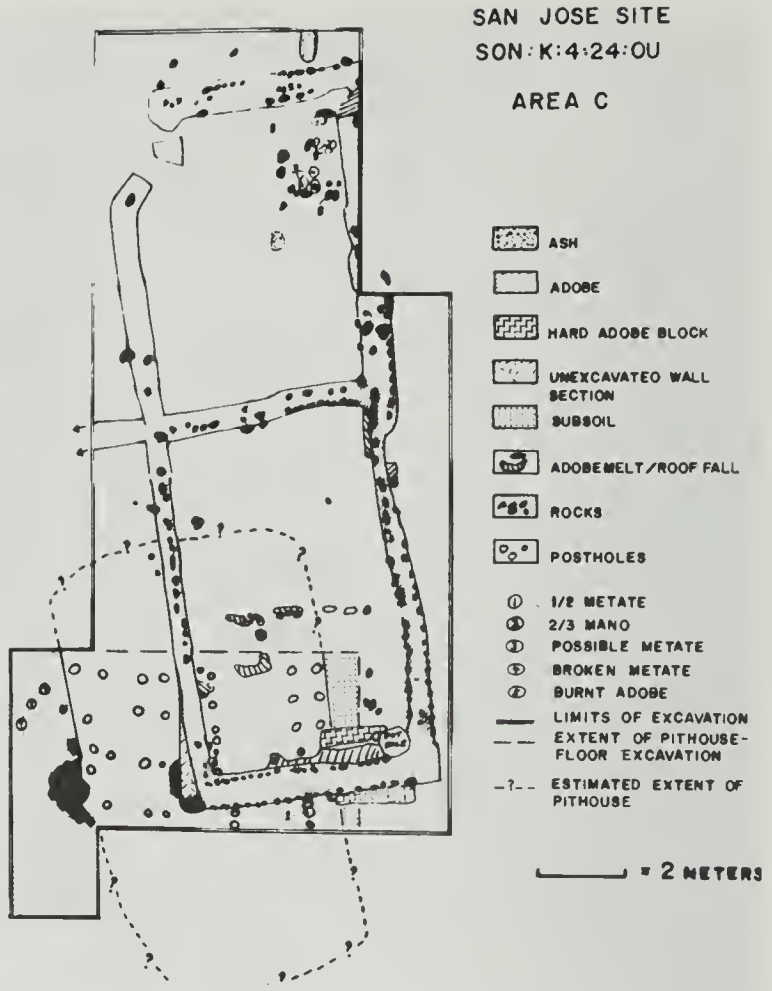

Fig. 9. Surface structure overlying house-in-pit. The adobe block entry right, with the surface structure wall between the adobe blocks. The deep portion of the excavation in the foreground, with numerous postholes, is the house-in-pit floor.

Fig. 10. Plan of surface structure with house-in-pit underlying the south end.

of stone, aproximately 2.0 m. in diameter, situated at the end of a high ridge overlooking the valley. The sites are located several kilometers apart, each in sight of the next one to the north and south. At least one contained small amounts of charcoal, but unfortunately not in recoverable form.

The ceramic analysis has been hampered by the excessive abundance of pottery that has been produced by our excavations, in spite of the fact that we really have not excavated very much of any one site due to a relatively small crew. We have been averaging about 250,000 sherds each summer season. The house in a pit described above alone produced in excess of 100,000 sherds These very high sherd counts were found only at the three large sites, in particular the San José site. Clearly, the occupants of these sites were participating in some special activity which involved an intensive use of pottery, and this is currently being explored in our analysis.

Due to the exceptionally high sherd counts, we have not yet worked out a ceramic typology that can be used in conjunction with the architecture for phase identification. Nevertheless, there are certain ceramic attributes that bear directly on the question of trade relations.

Elsewhere I have argued that Amsden's original idea of a Rio Sonora culture should be extended to include all of eastern Sonora and even into northern Sinaloa on the south, and that in the north it is linked directly with the Chihuahuan culture province and Casas Grandes. The surface structures such as the one shown here were one of the characteristics of Amsden's Rio Sonora culture, and they are found at least as far south as the Sahuaripa valley. Similar, but not identical, houses are also found in southern Sonora.

A second of Amsden's criteria for the Rio Sonora culture was the use of surface texturing, in the form of incising, as the primary means of ceramic decoration. Again, such incised pottery is found throughout the eastern foothills of Sonora and into northern Sinaloa. Furthermore, the incised ceramics as far down as the southern Sonora border are indistinguishable from Convento Incised and Casas Grandes Incised found in northwestern Chilhuahua.

The incised pottery constitutes 99% of the locally made decorated pottery, the other 1% consisting of a crude, red/brown similar to early Mogollon painted pottery. All decorated pottery represents about 4% of the total sherd count.

The incised material can be divided into three categories, which we eventually hope to reduce to more detailed types. The first is plain incised. Rectilinear incised patterns are applied on the exterior of jars and ollas between the rim and shoulder. There is considerable complexity to the patterns, and the execution runs from very fine to crude. Some lines appear to have been incised with a sharp instrument, others with a blunt one, and everything in between. This group is indistinguishable from Convento Incised and Casas Grandes Incised. It is also the only decorated type found in the foothills of southern Sonora (Fig. 11).

The second group is essentially similar to the plain incised, but with the addition of polished red zones included in the decoration. In some instances, the red is a function of polishing and firing, in others a red pigment has been added (Fig. 12).

The third group is characterized by the use of punctates, either with or without incised lines and with or without the red polished zones (Fig. 13).

These latter two groups are typologically the same as Playas Red Incised and Punctate from the Chihuahuan culture province, although there is probably enough difference to identify local varieties.

When we put these textured ceramics together with architecural forms, we have something comparable to DiPeso's early Viejo Period in Chihuahua, not necessarily in terms of time dimensions, but culturally. In effect, from approximately 1000 A.D. on, northeastern Sonora is culturally Viejo Period of the Chihuahuan province, followed by culturally Medio Period but without the elaborate developments characeristic of Casas itself. Rather, it is like a frontier, off-in-the-outback

Fig. 11. Plain incised sherds from the upper Rio Sonora valley.

Fig. 12. Red incised sherds from the upper Rio Sonora valley.

Fig. 13. Incised and punctate sherds, with and without red paint, from the upper Rio Sonora valley.

version of Chihuahuan culture. However, in the Rio Sonora valley at least it seems to begin later than in Chihuahua. this suggests the possibility that it represents a westward expansion, perhaps triggered by the developments that make the Medio period at Casas Grandes.

Another bit of evidence to support the suggestion of a westward expansion is the fact that in Chihuahua a number of texturing techniques are present in addition to those mentioned. A number of textured types are characterized by polishing over the incisions, e.g., Convento Rubbed Incised, etc. Also there is corrugation, corrugation combined with incising, etc. These do not occur in the Rio Moctezuma or further west and south.

As we move further south, the red incised drops out, and only the plain incised is produced. One of the characteristics of an expanding frontier is that the frontier culture becomes increasingly simpler than that from which it started.

Recalling the settlement pattern data again, it is also characteristic of a frontier for a nested hierarchy of hamlets, villages, towns, etc., to be absent. In its place there tends to be a frontier town serving all the surrounding hamlets, or in other words, one dominant site, numerous smaller sites, and no intermediate sites.

If this interpretation is correct, it is probably significant that the area encompasses the north-south trade routes. In effect, peoples related to Casas Grandes controlled the routes north.

Tradeware represents approximately 3% of all decorated pottery in our collections from the Rio Sonora valley. Of these, 91% consists of Chihuahuan polychromes and includes virtually the entire series: both Capulin and Standard varieties of Ramos polychrome, Carretas polychrome, Huerigos polychrome, Dublan polychrome, Babicora polychrome, and Villa Ahumada polychrome.

Significantly, Chihuahuan polychromes were traded into the Trincheras area as well, but incised pottery was not. This is what we could expect if both the Trincheras people and those on the Rio Sonora were getting their Chihuahuan pottery from a distance in trade but were not trading with each other because of hostile relations, or in other words, if this represents a westward expansion.

Of the remaining 9% of trade ware, 3% has been identified as Santa Cruz polychrome from the Tucson basin and 1% represents a variety of other types from the Tucson basin and other parts of the Southwest, including Gila Polychrome and Tularosa Black on white. Finally, the remaining 3% of trade ware represents Guasave Red from Sinaloa and few unidentified sherds which come from further south in west Mexico.

Exotic artifacts which represent trade items include:

Four copper tinklers and one copper crotal. One tinkler was found in a small site neighboring the San José site, the other three are from the San José site.

Fifty-four tourquoise beads found in the fill of a small site across the river from the San José site, but which lacks evidence of architectural features. Five additional beads from a small site north of Banamichi were found in an historic burial, probably dating from the early Spanish period. Two turquoise beads found on survey in the Baviácora-Aconchi segment of the valley have been identified as coming from southwestern sources, one from the Cerillos mine, the other from the Azure mine, both in New Mexico (Weigand, personal communication).

Fragments of shell, including shell bracelet fragments, from most sites.

Five figurine fragments and one effigy vessel fragment may or may not be trade items (Fig. 14). In any case, they certainly represent Mesoamerican concepts.

When we compare the distribution of these trade items, of copper, turquoise, Chihuahuan polychromes, and some shell, with our four models of trade, we find that a pattern is beginning to emerge. The San José site is clearly the dominant site in the Baviácora-Aconchi segment of the valley, and is the location of a large public structure which probably served the surrounding smaller sites.

However, almost all the sites tested have produced at least some Chihuahuan polychromes. None of the turquoise has been found in the San José site, and although four of the five copper items have been found there, the sample is too small to be indicative. This suggests that either the

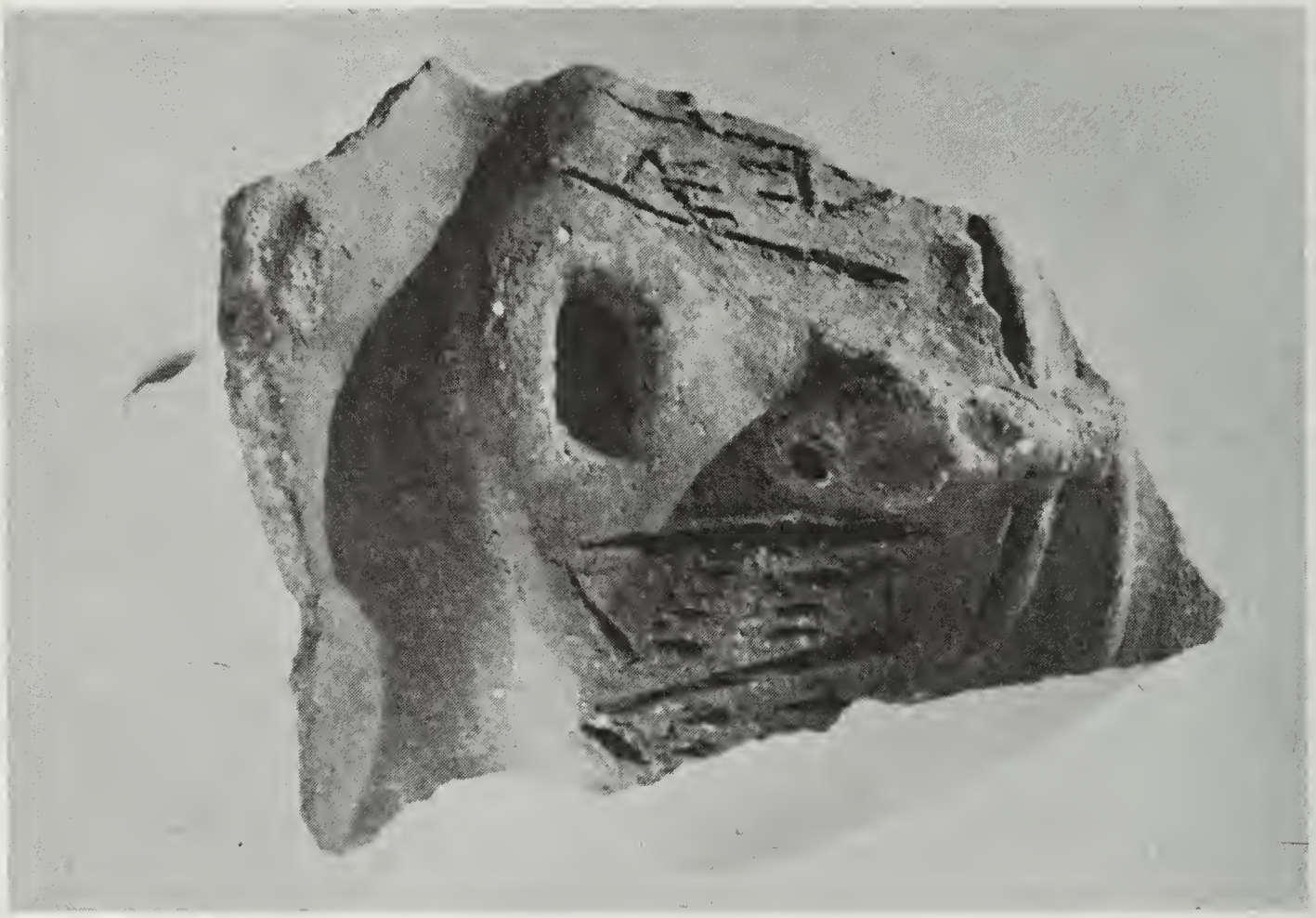

Fig. 14. Fragment of effigy vessel from the San José site.

San José site did not have a monopoly on foreign trade or, more likely, that it served as a redistribution center locally.

One question always raised is what was given in exchange? While we frankly do not know, one suggestion can be made. A total of 22 whole and ten fragmentary stone spindle whorls has been found (Figs. 15 and 16). Of these 59% come from San Jose, and eight are decorated. Although this does not seem like a large number, when taken in terms of the number of structures excavated to date, and in comparison with sites in other parts of the southwest, it is significant. As an example, no modelled spindle whorls, either of stone or ceramic, were found at Casas Grandes. In addition, several modelled ceramic whorls and numerous perforated sherd spindle whorls were recovered, although a complete count is not immediately available. Three stone spindle whorls were found in the floor of pithouse B-II, where there was also found pollen evidence of rumex, a plant material that is reported to have been used as a dye for cotton. Ethnographic data indicate that the Opatá were excellent weavers. Also they had special subterranean houses in which basketry was made. It is entirely possible that weaving was also done in such houses. We are currently exploring the proposition that a local specialty was the production and processing of cotton as a trade item.

Testing the postulated model of a Mesoamerican world system is more general than the above propositions concerning trade systems, and probably cannot actually be done on this project alone. Rather, this project and others like it in the Southwest and northwest Mexico will together contribute to such a test. Basically, this involves determining if the Southwest was in fact a part of a larger system which included Mesoamerica; not simply was it in contact with Mesoamerica, but whether or not the relationship was a systemic one. By the nature of a system, changes or events in one part should affect changes in another. However, Wallerstein's model, and the Pailes and Whitecotton Mesoamerican adaptation of it, describe a system characterized by unequal parts. Hence, events in the Mesoamerican core would be expected to have exaggerated effects on the southwestern periphery, while events in the periphery would have little effect on the core.

Certainly, if trade networks between Mesoamerica and the Southwest can be identified, and if these in turn can be shown to influence local cultures in the Southwest, then a systemic relationship will be demonstrated. In that event, unless someone has the temerity to argue that the Southwest was the equal of Mesoamerica, an unequal system such as Wallerstein's is indicated.

Fig. 15. Stone spindle whorls from the upper Rio Sonora valley.

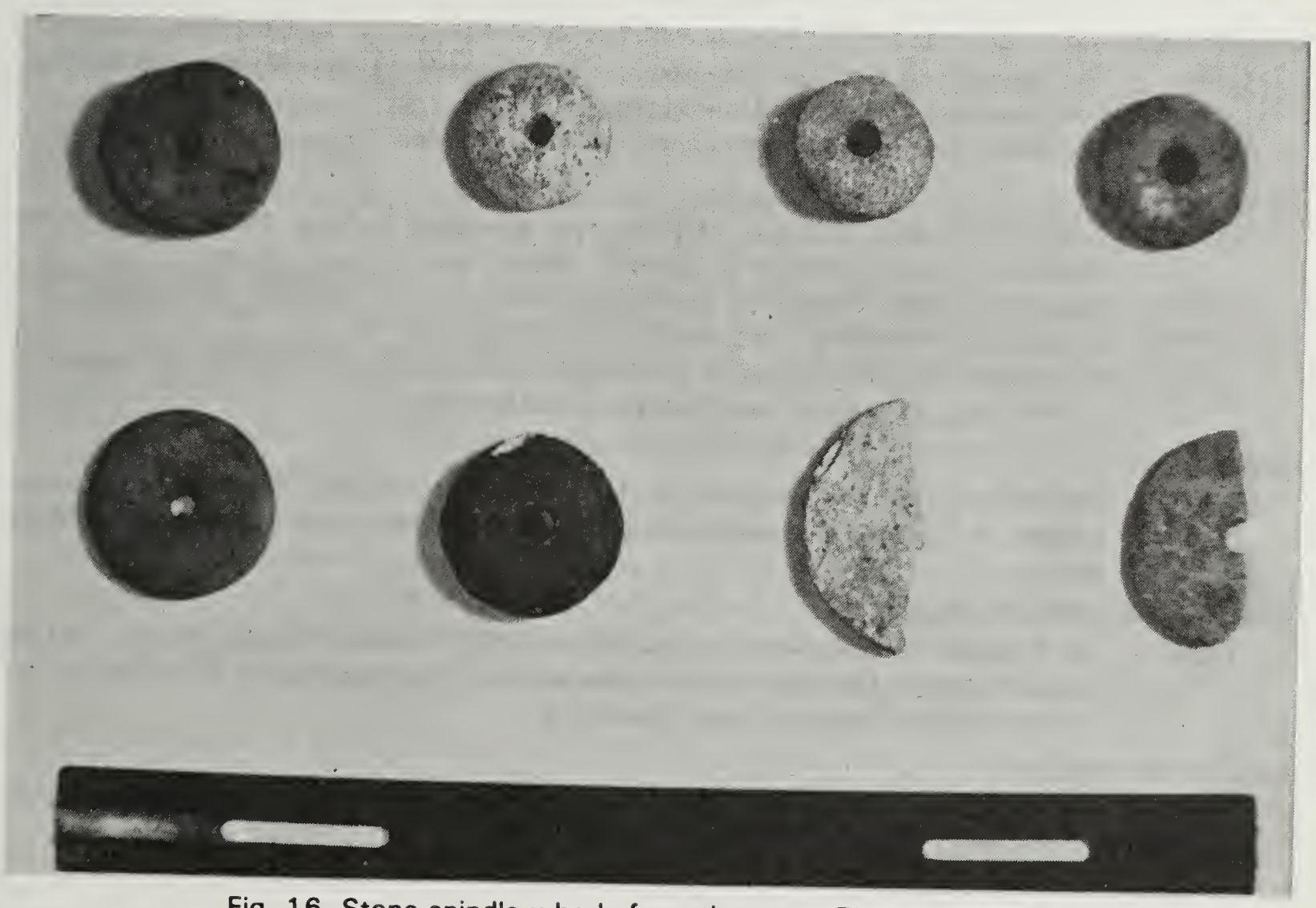

Fig. 16. Stone spindle whorls from the upper Rio Sonora valley.

Notes:

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THE PREDICTIVE DIMENSION OF PRIESTLY POWER

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ABSTRACT

Pueblo priests used esoteric knowledge to predict seasonal changes and astronomical events, and their power increased or diminished with their ability to "control" these phenomena. Inaccurate predictions often resulted in discord and possibly in charges of witchcraft. The use of this ethnographic/ethnohistoric model for studying prehistoric Anasazi sites is discussed.

THE PREDICTIVE DIMENSION OF PRIESTLY POWER

> The man who went to the Sun was made Pekwin[3] [[3]Pekwin "cares for the sun." He observes its movements to determine the ceremonial dates.] The Sun told him, "When you get home you will be Pekwin and I will be your father. Make meal offerings to me. Come to the edge of the town every morning and pray to me. Every evening go to the shrine at Matsaka and pray. At the end of the year when I come to the south, watch me closely; and in the middle of the year in the same month, when I reach the farthest point on the right hand, watch me closely." "All right." He came home and learned for three years, and he was made Pekwin. The first year at the last month of the year he watched the Sun closely, but his calculations[1] [[1]For the winter solstice] were early by thirteen days. Next year he was early by twenty days. He studied again. The next year his calculations were two days late. In eight years he was able to time the turning of the sun exactly. The people made prayersticks and held ceremonies in the winter and in the summer, at just the time of the turning of the sun. (Benedict 1935:II:66-67)

The ethnographic and ethnohistoric literature for the southwestern Pueblos contains many accounts such as the one above, accounts which describe how Pueblo priest come to power, their duties and responsibilities, and the consequences of their behavior in terms of the behavior of the inhabitants of their villages. Despite almost 400 years of acculturation, many of these activities continue today, albeit in attenuated forms.

One major duty of the priest is astronomical observation. Except at Laguna, where the native astronomical practices have ceased, each pueblo has an official "sunwatcher" who makes and records apparent solar movements (Ellis and Hammack 1968; Parsons 1939; Reyman 1971, 1975, 1976a, 1976b).

> As is the case with all other agricultural people, the Pueblo Indians are dependent to a great extent upon the sun. Consequently, they are intensely interested in the sun's movements. (White 1942:205)

At some pueblos, the same official is also responsible for lunar and stellar observations; at other towns, another priest or group of priests has this duty (e.g., Bunzel 1932; Parsons 1939; Reyman 1971; Stephen 1936; Stevenson 1904). The data from astronomical observations, in conjunction with observed changes in flora and other natural phenomena,[1] are used, in part, to establish and maintain calendars for the scheduling of subsistence activities and for the organization and ordering of the associated socioeconomic and ritual behaviors, e.g., irrigation ditch maintenance, field preparation, communal collecting and hunting activities, and katsina dances (e.g., Beaglehole 1937; Benedict 1935; Bunzel 1932; Forde 1931; Fewkes 1920; Parsons 1939; Reyman 1976b; Stephen 1936).

Observations of stars along the ecliptic are also used as nighttime checks on the sun's position. These observations are most useful in winter when sunrise and sunset are often obscured by clouds or other adverse weather conditions, sometimes for several days in succession. Finally, observations of bright stars—most commonly the Pleiades, the belt of Orion, the Sirius—and observations of Venus, both as Morning and Evening Star, are frequently used, especially among the Hopi and Zuni, to time parts of ceremonies, i.e., the appearance and disappearance of these stars in the night sky, often observed through kiva hatchways, are taken as signals by the priest(s) to begin or end an aspect of a particular cemermony. For example:

> About three, Orion was spoken of as being high enough in place, and all the inmates of the chamber took up their prayer sticks from the various trays along the pollen trail, and, with their rattles, etc., Si´mo leading with his moisture rattle, all went out to Antelope mound court. Venus is just well clear of the horizon. (Stephen 1936:813)
>
> When Orion got about due south as seen from the floor through the kiva hatch . . .Su´pelă . . .made three lines with prayer-meal and set the crenellate bowl in the centre, . . . (Stephen 1936:890)
>
> The Pleiades were just overhead, but in the south, and the moon had just fairly risen when the altar ceremonies began. (Stephen 1936:891)
>
> They are waiting for the Pleiades to come overhead . . . and at 10:40 the Pleiades and Orion (Wutom´kami) were overhead. Anawi´ta . . . said when Pleiades got over there, pointing about and hour and a half ahead, come back here and go with us to Singers kiva. (Stephen 1936:969)
>
> Just as the morning star was rising, the music ceased, the congregation became silent, and the chief dancer was led to the center of the room, where he was elaborately costumed. (Cushing 1967:26)

These aspects of Pueblo ceremonialism are discussed at length in the above mentioned sources, and I have also considered them in conjunction with research on the sunwatchers, *per se* (Reyman, 1971, 1976a, 1976b).[2]

PUEBLO ASTROMOMY AND THE CORRELATES OF PRIESTLY BEHAVIOR

This paper is addressed, however to other issues: The consequences of both accurate and inaccurate predictions by priests[3] of astronomical events such as the solstices; the kinds of behavior which follow when the seasonal changes occur in the environment as predicted by the priests; the nature of the people's response when seasonal changes do not follow expectations. Ethnographic data are available which can be used in the analyses of these issues, i.e., toward the study of material results or correlates of priestly behavior. These same data are also useful for research into prehistoric contexts.

It must be noted here that this paper is a preliminary statement based on current research (Reyman ms.) and that both the general framework and specific aspects may be revised as the work progresses. Thus, this paper should not in any way be viewed as a final analysis; rather, it is meant to stimulate discussion and other research toward a better explanation of the data.

Generally, the Pueblo complexes discussed herein are best understood if the reader keeps in mind that they operate as systems of checks and balances: Priestly orders check the power of each other and are, in turn checked by the villagers; society memberships (medicine, war or scalp, katsina, etc.) crosscut village organization and bind people to the ceremonial groups headed by the priests. This checks or places limits on dissent; priests can reduce threats of their positions by suggesting that they will not perform the important ceremonies for which only they have the required secret knowledge; and nature serves as the ultimate check on all because climatic conditions and seasonal changes are not as predictable as expected or desired. Therefore, the ethnographic data, although discussed under several categories, should be understood as integral elements within the larger Pueblo sociopolitical and economic context.

The Western Pueblos. The Hopi and Zuni have more complex astronomical systems than do the eastern Pueblos. Not only do these western peoples make careful solar observations, but they also watch closely the movements of the moon and stars. As noted above, stellar movements are used as timing mechanisms for ritual activities (Venus, a planet, is considered to be a star)[9]

Both the Hopi and Zuni attempt to coorelate their solar and lunar calendars.

> . . . it was easy task for the Hopi to keep their calendar straight . . . partly because they tried to reconcile lunar and solar phases. The attempt to fit thirteen moons evenly into the two equal periods of time between the solstices of the year was over-ambitious . . . it was not unusual for the men in charge to skip or lose track of a moon in their count. (Titiev 1938:39)

During the past several hundred years, perhaps starting as early as A.D. 1000,[10] the Hopi sunwatchers developed highly accurate solar horizon calendars. The priest use these calendars to predict seasonal changes in the environment, most often in terms of weather conditons, and to announce the best times for planting, the concomitant ceremonies, and the various other socioeconomic activities on which village life depends (e.g., Beaglehole 1937: Forde 1931; Parsons 1925, 1933; Stephen 1936; Titiev 1938)." These horizon calendars are also used by the priests in their efforts to reconcile or synchronize solar and lunar movements. Previously, calendrical errors such as the loss of a moon in the lunar count were regarded as catastrophies and were thought to cause bad weather (Titiev 1938:39, 39 n. 1). Also,

> We think the Sun-watcher is not a very good man. He missed some places, he was wrong last year. And I think he is going to miss or take on some place (i.e., to observe inaccurately). all the people think this is why we had so much cold this winter and no snow. (Parsons 1925:75)

Traditionally, calendrical errors followed by bad weather often caused sanctions to be brought against the *ta´wa moñwi˜* (Sun Chief or sunwatcher), including charges of witchcraft. Witches are universally feared among the Pueblos and are thought to be responsible for all sorts of misfortune such as crop loss and bad weather. Anyone may be a witch, even priests or one's closest relatives (e.g., Parsons 1939; Simmons 1942). As Parsons (1939:154) notes, ". . . chiefs are peculiarly open to the change of witchcraft. 'The best men of the pueblo may be witches' (Laguna)." Ultimately, a witch may be killed, especially when the conditions which precipitated the charges of witchcraft do not improve, or if additional misfortune should occur.

When observational errors or calculation mistakes are made, corrective measures, usually in the form of special ceremonies, can be taken to compensate for the errors (e.g., Parsons 1925, 1939). Vigorous attempts are made through these rituals to restore balance and harmony—homeostasis—to the system. During such time, priests are expecially careful when making their observations.

> . . . Snake chief says that he wants to call out as soon as sun gets to the place. So he has to watch very closely. He wants to do what is right. He wants to do his best. (Parsons 1925:101)

In recent years, however, with the decline in the importance of farming and a weakening of the traditional culture, calendrical errors have caused fewer serious consequences. Rather, teasing and joking may take place, village life is no longer disrupted, and charges of withcraft no longer seem to be made against the sunwatcher, as was once the case.

> At Hotevilla in 1933-34, the loss of a moon delayed the performance of the winter rituals approximately a month beyond the celebration of the same ceremonies at all other Hopi pueblos. Much teasing was exchanged back and forth, but no serious objections were raised. In the spring, the officers of Hotevilla recognized their error and skipped a moon in order that the planting dates might get back to schedule. (Titiev 1938:39 n. 1)[12]

Much the same sort of astronomical system is found at Zuni, with one added element—the winter solstice should coincide with the full moon:

It seems likely that Pueblo priests use their esoteric knowledge of astronomical phenomena to increase their power and prestige. Predictions of the sun's reversal of its apparent movement along the horizons are politically important; when successful, these predictions increase a priest's power because they demonstrate his ''control'' of astronomical phenomena and, to some extent, of the cosmos.

> . . .it may be that the time set for ''calling the sun back'' intentionally preceded the true solstice in order that it could be claimed that the recall was actually achieved. Similarly, late in the fall, after the main harvests, the reversal of the sun's course along the eastern horizon might have been intentionally anticipated in an effort to impress laymen with the powers of the medicine societies. (Lange 1959: 321-322; cf. Titiev 1960).

Pueblo astronomy is far from a monolithic system, however, and marked differences are present in native astronomical practices as one moves from village to village. Some of these differences probably originated in prehistoric times and the early historic period as results of different responses to local environmental factors.[4] Other differences may have resulted from the operation of one or more complex, and as yet poorly understood, historical processes including village disintegration (Old Oraibi), the development of outliers (Moenkopi), interpueblo marriage and migration (Pecos to Jemez), fusion (Zuni), and so forth. Still other aspects of this variation can be attributed to the differential effects of Spanish and later acculturative pressures on the individual pueblos. Nevertheless, today at least two levels of complexity are discernible.

The Eastern Pueblos. The simpler systems are found in the eastern Pueblos. At Taos, Jemez, among the Keres,[5] and the other eastern villages, it is believed that the *cacique*[6] ''controls'' the sun's movements and can direct their reversal, when necessary. At times, especially in winter, the priest performs rituals to speed the sun's movement northward, to hurry the arrival of summer: ''Sometimes the Masewi hurries it [the summer solstice] to make the summer longer.'' (White 1942:205; cf. Titiev 1960).

Most of the eastern Pueblos recognize the moon, often consider it a deity,[7] and have named lunar months as at Taos (Parsons 1936, 1939). Nevertheless, the moon is relatively unimportant in terms of precise astronomical observations (e.g., Goldfrank 1927; Lange 1959; Ortiz; White 1932a, 1932b, 1942, 1962).

> In contrast to a popular conception of American Indian ''moon counts'' for months of the year, it is interesting that no such reckoning is found among the Cochiti. Modern references to the months of the year are in Spanish or English, and there is no Keresan counterpart; this appears to be true in the past also. The word for *moon* is ta watsh; *month* is tzash'tye-ta'watsh, and there appears to be no elaboration of these terms. (Lange 1959:322)[8]

Stars are also recognized and observed, especially Venus as both Morning and Evening Star, the Pleiades, Orion, and the Milky Way (Parsons 1939; Reyman 1971, 1976b; White 1962); but stellar observations are secondary to sun watching. Although it is possible that some ethnographers overlooked the importance of astronomical observations other than solar ones, the general paucity of data on lunar and stellar record keeping suggests that, at least in recent years, priests in the eastern Pueblos spend relatively little time observing astronomical phenomena other than the sun (Ellis 1975; Reyman 1971). Finally, the statements of Pueblo informants support this inference. The *cacique* and other priests are spoken of as controlling the sun's movements, not the movements of other celestial bodies.

Of course, the *cacique* and other priests do have ''real'' political control over various village activities, including many connected with farming; also irrigation and other water control systems do

effect productivity. Nevertheless—and this may be a ''chicken-and-the-egg'' problem—it seems that the development of significant priestly power *first* resulted from accurate predictions of seasonal changes which, in turn, permitted more efficient scheduling maintenance work on irrigation ditches, water control gates, and so forth (Lange 1959). Thus ''real'' control developed from ''apparent'' control, after which the two systems appear to have reinforced each other.

> However, the Zuñis seem never to have been able to decide on the relative merits of solar and lunar calendar [*sic],* and the desire to have the observation of the solstice occur at the full moon disarranges the calculations and naturally leads to dissention [*sic]* among the various priests. However, the date is definitely set by the Pekwin and the others, whatever their views, fall into line. (Bunzel 1932:534)
>
> The p̂ekwin is the most revered and most holy man at Zuñi. Even in this society which diffuses power and responsibility until both become so tenuous as to be almost indiscernible, the p̂ekwin is ultimately held responsible for the welfare of the community . . .
>
> As priest of the sun he is keeper of the calendar. He sets the dates for the solstices, from which all other ceremonies are dated. His calculations are based on observation of the sunrise in winter and the sunset in summer. These observations are made at shrines outside of the village. When the sun rises (or sets) behind certain landmarks, the date for the solstice is at hand. However, the calendar is disarranged by the desire to have the celebration of the solstice coincide with the full moon, and the p̂ekwin is the subject of bitter criticism when the sun fails to oblige in this matter. (Bunzel 1932:512)

It must be noted that it is *impossible* to reconcile the solar and lunar calendars (cycles) so that the winter solstice always coincides with the full moon. In fact, these two events do not occur together even half the time. The Zuñi and Hopi priests cannot possibly accomplish what they ultimately seek to do and what is apparently expected of them. Furthermore, contrary to Stevenson's (1904:393) contention that few except the poor and unfortunate are tried for witchcraft, at Zuñi, as at Hopi and many other pueblos, a priest who fails in his duty may find himself accused of witchcraft. As Stevenson notes on the same page:

> Several years ago the droughts were very serious, and a retired sun priest was suspected and impeached, and his place was filled by another. The people whispered among themselves, ''He is a sorcerer.'' (Stevenson 1904:393)

The underlying reason why the priests must fail more often than not in their efforts to reconcile the solar and lunar calendars at the winter solstice is that there is a basic 19 year periodicity in the conjunction of the two cycles. This periodicity, however, is internally variable, mainly because one needs to round off the solar year (365.242199^{+}days) and the lunar month (29.530588^{+}days), neither of which is a whole number or evenly divisible by the other. This rounding problem, plus several astronomical factors, cause a shift in the calendar date of the winter solstice: It occurs usually on 21 December, but occasionally falls on 20 December or 22 December.[13]

Several other points must be made. First, given the stated goal of having the winter solstice coincide with the full moon, the best that the Zuñi *p̂ikwin* can hope for is that the two events will correspond 5 times every 19 years (3,5,3,3,5 years); the worst is that the two events will coicide only once in 19 years. Thus, the *p̂ekwin* will be wrong most of the time. The Hopi do not seek as great a degree of precision in this particular situation. Yet, the Hopi, too, must fail in the majority of their attempts to reconcile the solar and lunar years (calendars).

Second, ethnographic data indicate that the Pueblos had tally sticks and other record keeping devices (e.g., Cushing 1967; Stephen 1936) in addition to their horizon calendars and astronomically aligned features. However, there is little to indicate that they had a mathematical system sophisticated enough for long-term record keeping and for the interpolation required for accurate predictions of winter solstice—full moon coincidences. The lifetime knowledge of the *p̂ekwin,* for example, would be of relatively little value to his successor when the pattern shifted

from one sequence to another, as from once in 19 years to 11,8,11,8 years, or from 8,3,8 years to 11,8 years.

Third, the frequent failure of the priests to control, as expected, the sun and moon means that dissension must be common within the ceremonial societies and within the villages in general. The same was true historically. Indeed, such dissension appears to be endemic and may contribute to the factionalism which *is* endemic at so many pueblos.

Fourth, the usual lack of correspondence between the winter solstice and the full moon may help us to explain the shifting date of the Zuñi *Shalako* (Ellis and Hammack 1968), and this may also be a factor in the traditional existence of both "long" and "short" forms of the major ceremonies. These two forms, e.g., 8 days versus 4 days[14] are, perhaps, one means of reconciling the solar and lunar calendars.

Fifth, given the relatively infrequent coincidence of the winter solstice with the full moon, there is at work a "natural" check on priestly power. The inability of the priests to make accurate predictions all the time and the fact that this is due to the natural situation which is beyond their control (insufficient mathematics) places one check on the expansion of priestly power.

Sixth, this same lack of coincidence leads us to ask how or why people at Zuñi came to expect that the *p̂ekwin* would routinely "cause" these two events to happen together? This is discussed later.

Seventh, aside from the particular problem of the winter solstice - full moon coincidence, the Hopi and Zuñi priests have been generally successful in their observations and calculations. Furthermore, the respective systems have worked well as results of their behavior. This is, perhaps, sufficient to explain the persistence of the behavior, once established.

THE REALITY OF PRIESTLY "CONTROL"

The issue of the reality of priestly "control" of astronomical phenomena and events requires further discussion. From the Pueblo *emic* perspective, i.e., on the basis of informants' statements such as those regarding priests' duties and abilities, there is no question that the Pueblos "believe" their priests control the sun's movements and can also control weather through the use of proper ritual. Yet the same informants, as reported in the ethnographic literature, are obviously aware of their priests' fallibility in these matters:

> Nor may the Sun Priest err in his watch of Time's flight; for many are the houses in Zuñi with scores on their walls or ancient plates embedded therein, while opposite, a convenient window or small port-hole lets in the light of the rising sun, which shines but two mornings in the three hundred and sixty-five on the same place. (Cushing 1976:41)

If the Pueblos recognize that their priests make mistakes, why then do they state that they believe the priests control these astronomical phenomena and events?[15] Furthermore, why do they expect certain things to happen regularly, e.g., the winter solstice - full moon coincidence, when their grossest empirical observations indicate otherwise? These questions lead to others: How do priests obtain power? Or why does the group cede power to a few of its members? I have no definite answers, but two complementary hypotheses can be suggested here.

First, it is in the Pueblos' self-interest to believe in or to assume priestly competence. This permits the societies to function more smoothly than would be the case if every pronouncement by the priests was questioned or disregarded until it was empirically confirmed. Where central authority is weak,[16] as at Hopi, the priests are the political officials to whom, along with the clan heads (sometimes these are the same people), the villagers look for stability. It would be contradictory and self-defeating if the Pueblos did not cede competency and power to their priests until such time as this trust was violated.

Second, priestly power may often reduce the devisive effects of the endemic factionalism, although, in some cases, the priests may side with a particular faction (Titiev 1944). Usually, however, the head priests—*cacique, p̂ekwin,* etc.—are expected to remain apart from such mat-

ters (Lange 1959; White 1942). If a priest becomes too powerful, or obviously incompetent, the situation can be checked by the secondary officials, e.g., medicine society leaders, Bow and Rain priests at Zuñi, the katsina impersonators. Ultimately, charges of witchcraft can be levelled against those who do not conform to public expectations.

Perhaps more to the point is that, with the notable exception of the winter solstice - full moon problem noted above and the problem of prolonged adverse weather conditions such as the 1892-1904 drought at Old Oraibi, the Pueblo systems generally work. Regardless of the origin of priestly power, once in office, the priests have kept that power and expanded it through careful and successful manipulation of the system. They have learned to make accurate astronomical observations and to plan village activities accordingly. They are able to "stack the odds" for a good harvest in their favor: Successful crop production generally follows from their predictions and directives (Reyman ms.). Katsina dances and other ceremonies are scheduled so that food is distributed as needed, especially when supplies are low for the village in general. Good weather and careful calculations allow for a continuance of power and control. Empirically, such conditions occur often enough to reinforce the behavior. This provides a sufficient explanation for its persistence and is a good example of how "the logic of the irrational" often leads to an understanding of the underlying rationality for the observed behavior (e.g., Devons and Gluckman 1964; Spiro 1966). Priestly power and control simplify the decision making process, facilitate group cooperation, and alleviate, at least to some extent, intrapueblo devisiveness.

Finally, there is the matter of the process by which events such as the winter solstice - full moon coincidence come to be expected. The following is suggested as one possibility.

It could have happened that, at some point in Zuñi history, the *p̃ekwin* thought it possible to calculate the simultaneous occurrence of the two events. Perhaps he noticed that they coincided during a particular year. Given that the sun appears to stand still for 3 or 4 days at the solstice, the *p̃ekwin* may have thought it possible to correlate this standstill at the winter solstice with the appearance of the full moon. As noted earlier (see note 13), the pattern of coincidence varies with the years and with the number of days (^{2}) one allows for the events to coincide. If the *p̃ekwin* calculated the date of the solstice and allowed as many as $^{2}3$ days as a margin of error, and did this during one of those periods when his calculations seemed to achieve maximum results—5 coincidences in 19 years—then the prediction and the expectation of coincidence may have found their way into the astronomical system. One such favorable period occurred from A.D. 1485-1534 (see Table 1). The next two years of coincidence would have been A.D. 1542 and 1550, although neither coincidence would have fallen precisely on the winter solstice; 1542 would have been one day late, and 1550 would have been two days late. The Zuñi may have even considered this shift to 8 year intervals to be a sign that their relationship with the universe had been disrupted, that harmony had been disarranged, by the *entradas* of de Niza (1539) and Coronado (1540-1541).

Nevertheless, during the period from A.D. 1485-1534, coincidence may have occured often enough for the *p̃ekwin* to predict it and for the people to have believed him. Heavy clouds, which are common in winter, could have helped the *p̃ekwin* by obscuring observations, thus making the situation seem ot occur more often than it actually did. In any case, the expectation became fixed in the Zuñis' minds to the point that problems arise when the the two events do not coincide. Finally, it is possible that the people now manipulate this expectation to make the *p̃ekwin* more aware of the limitations to his power (if this hypothetical situation seems fanciful—and it is—bear in mind the circumstances surrounding the arrival of Cortez among the Aztecs).

THE CORRELATES OF PRIESTLY BEHAVIOR

As we have seen, the western Pueblos have more complex astronomical systems than do the eastern villages. The two groups also differ in other ways, and these differences are often explained in terms of specific historical and environmental factors (cf. Eggan 1950; Ellis 1964; Fox

1967). The two levels of complexity in the respective astronomical systems may also be results of these same factors, particularly the environmental ones. Following Eggan (1950), I suggest that the eastern Pueblos, situated along the Rio Grande and its tributaries, a generally more favorable environment for farming and hunting/collecting activities than the more arid environment of the western Pueblos, did not require the more complex and precise astronomy found at Hopi and Zuñi. For example, horizon calendars are used in both areas, but they are more complex among the western Pueblos, i.e., topographic features are used to mark a greater number of days in the solar year. The Pueblos in both areas recognize many of the same stars and use them for timing ceremonial events; but the western Pueblos recognize more stars, use them in more ways, and strive for greater precision than do the eastern villagers. In short, the somewhat more marginal environment of the western Pueblos has, in part, given rise to a more elaborate system of astronomy in relation to adaptation than is found among the eastern Pueblos. The same sort of dichotomy is apparent in their respective ceremonial societies: In the West, the main function is rain-making, while in the East it is curing (Eggan 1950).

Table 1. Winter Solstice - Full Moon Coincidence, A.D. 1485 - 1534

Year	Date of Full Moon	Years Between Dates of Coincidence
1485	21 December	
1488	19 December	3
1493	23 December	5
1496	20 December	3
1501	24 December	5
1504	21 December	3
1507	19 December	3
1512	23 December	5
1515	21 December	3
1520	24 December	5
1523	22 December	3
1526	19 December	3
1531	24 December	5
1534	20 December	3

It may seem paradoxical that the West, with the more complex system, should be less successful than the East. I suggest that the solution to the paradox is found in the respective environments. The eastern Pueblos have a comparatively more reliable water supply than the western Pueblos. Thus, the farming system is more productive more often than in the western villages. A current analysis of production figures for both areas, though still incomplete, tends to support this statement (Reyman ms.).

Regardless of the particular system under discussion, however, one thing is the same throughout the Pueblo area: A significant amount of Pueblo behavior follows directly from the specific announcements of calendric dates by the sunwatcher. These calendars are used to structure day-to-day activities within the villages, and the priests have charge of the calendars:

> Wonderfully reliable and ingenious are these rude systems of orientation, by which the religion, the labors, and even the pastimes of the zuñi are regulated. (Cushing 1967:41).

At Cochití, the *cacique,* through the *nahíya* (war chief) originally, but now throught he *síat yoyo* (war captain; also *masewi*), schedules the major village activities on the basis of his solar observations: Seed preparation, field preparation, irrigation ditch maintenance, planting, harvesting, etc. (Lange 1959). At one time, the *cacique* even controlled the movement of Cochití residents in and out of the pueblo (Lange 1959:251). The *cacique,* operating through the *masewi,* mobilizes and directs the village work force.

Among the Hopi, the predictions made by the *ta'wa moñwi* of the coming winter solstice set into motion a wide range of activities in preparation for the event and the accompanying *Soyala* (winter solstice) ceremony. In terms of Hopi behavior, the same sort of things happen as the dates are announced for the other major ceremonies, e.g., *Pá müriya, Powá'mu, Pa'lülükoñti,* including the necessary farming, hunting/collecting, and ritual behaviors. Here, too, the priests have considerable power over the village labor pool.

There are additional behavioral correlates. A successful harvest often requires that new storage facilities be constructed; conversely, a succession of poor harvests will cause abandonment of these units, usually starting with the least accessible ones. Many of the astronomical data are incorporated into the pueblo, *per se,* in the alignment of architectual features. A window or wall may be constructed or rebuilt so that looking through it, or along it, the priest can observe the winter solstice sunrise, sunset or some other event (Cushing 1967; Ellis and Hammack 1968; Lange 1959; Parsons 1939; Reyman 1971, 1976a). Buildings are often constructed or modified in accordance with the needs of this priest-astronomer.

Thus, the priests organize the cycle of subsistence and distribution activities on which the Pueblos depend. If they do their work well, if good weather prevails, and if crop production is high, their power and prestige increase accordingly.

Limiting Factors. In times of drought or other natural crises, the priests make additional attempts to regain control of the situation (see below). The people follow this lead by expanding the area for subsistence exploitation to include a greater variety of econiches, the better to increase their chances for food production. Indeed, the Pueblos usually plant (and also collect) in a number of distinct econiches, and at different times in the growing season or year, apparently as a ''hedge'' against both adverse climatic conditions and possible calendrical errors by the priests (Bradfield 1971; Titiev 1938, 1944; see below for further discussion). The general increase in the area used for farming may also require that new water control systems be built and that outlying small house units be constructed. But the range of environmentally permissable modification in the cycle is quite narrowly circumscribed by the relatively brief growing season.

Other factors affect the success of the system. First is the often weak and decentralized nature of Pueblo sociopolitical authority, notably among the western Pueblos. Even in the East, however, the *cacique* is not omnipotent. In some cases, as at Taos, there is dual leadership which switches every half year (Ortiz 1969; Parsons 1936, 1939). Moreover, it is the war chief who carries out the *cacique's* pronouncements; he can dilute the *cacique's* authority and may, at times, undermine it. The various medicine societies also serve as a check-and-balance system so that power is often in the hands of priests rather than in those of *a* priest.

A second problem is the apparent endemic Pueblo factionalism noted earlier. As at Old Oraibi (Titiev 1944), Pueblo priests may find themselves leading factions or having their work disrupted by factional disputes.

Third, as the Pueblos became increasingly dependent upon farming, a better understanding of seasonality was necessary. In an attempt to increase predictive accuracy, Pueblo priest-astronomers apparently began to observe more and more celestial bodies and astronomical events. Efforts were made to record these observations and to correlate both the cycle of the individual motion and the correspondences or coincidences among major events within two or more cycles, e.g., the heliacal risings of Venus and bright stars such as Sirius, or the conjunction of the winter solstice with the full moon. Such things are difficult to do.

Fourth, the periodicity of events such as the winter solstice—full moon coincidence is long and complex in its operation. The Pueblos' lack of sufficient mathematical capability means that calculations for and predictions of such events are usually incorrect. The priests' failure to reconcile the data from their observations can affect the accuracy of their other predictions of seasonal changes and the concomitant optimal times for the various subsistence activities. The resultant

confusion may, for a time actually *decrease* the efficiency of their calendars as adaptive tools. In other words, in their attempts to improve the calendrical system and to expand their power base, the priest-astronomers observe and record a greater number of astronomical phenomena which they do not have the capability to integrate into the system. Thus, in their efforts to upgrade their control and increase their power, the priests may, instead, incorporate within the system the seeds of possible disruption and, worse, their own failure.

Fifth, relatively short-term climatic changes, such as a slight shift in the frequency and amount of summer versus winter rain, or drought, with the accompanying effects on arroyo-cutting and water table levels, are not predictable from Pueblo calendars. These climatic shifts also tend to affect adversely the periodicity of the seasonal changes which are predictable. In turn, the rate of environmental deterioration may increase, a situation begun, perhaps, by overexploitation of the land. The consequences of these changes, i.e., the reduced efficiency of the calendars in terms of farming and other economic activities, place enormous stress on the system. Such stress can precipitate village disintegration, as happened at Old Oraibi (Bradfield 1971; Hack 1942; Titiev 1944) and elsewhere.

Sixth, as conditions deteriorate, as the priests are unable to regain control, the entire community is affected. Where resources are communally controlled and utilized, or if intercommunity importance, these environmental changes, if unchecked in their consequences, can reduce sharply the carrying capacity of the land, This, in turn, disrupts the occupation of an area or even forces a major exodus from an entire region. The so-called ''Great Drought'' in the northern Anasazi area during the late thirteenth century is a notable example of this (cf. Bradfield 1971; Zubrow 1974, 1975).

SUMMARY

As long as the *cacique, p̂ekwin,* or other head priest performs well his functions, as described above, he commands significant respect and power. Priests whose behavior produces the desired results for the villages also receive considerable material benefits. Although these rewards vary from pueblo to pueblo, some of the common ones include the planting and harvesting of the priests' fields by the villagers, multi-year food supplies, meat provisions provided through special communal hunts, use of an ''office'' for priestly duties, one or more assistants, and allotments of land reserved for personal use; these last can be used to reward supporters and ceremonial participants (e.g., Cushing 1967; Lange 1959; Parsons 1936, 1939; Stephen 1936; Titiev 1944; White 1932a). Formerly, at Cochití, the people of the pueblo built a new house for the *cacique* when he took office (Lange 1959).

Should the priests fail, however, because of errors in their calculations, mistakes in their behavior, or adverse climatic conditions, they probably will lose most of all of their benefits. They may also be forced from office and can even be killed if they are tried and convicted of witchcraft. It is also possible, though less likely, for some of the same things to happen if they are too successful. Finally, priestly incompetence combined with bad weather have, in the historic past, been responsible for the dissolution of pueblos, most notably Old Oraibi.

THE PREHISTORIC CONTEXT AND CHACO CANYON

The issue of site abandonment is discussed in almost every site report for the Anasazi area (and for archaeological sites in general), and the reasons for the depopulation of entire regions, such as the San Juan River valley, are matters of long-standing concern to Southwestern archaeologists. In conjunction with these problems, researchers are also concerned with the processes of site fission, the subsequent establishment of new pueblos by those who left the ''mother'' site, and the nature of the relationships among the peoples of these towns (e.g., Kidder 1924). These problems have been of particular concern for more than 50 years to scholars working at Chaco Canyon; of special interest have been the relationship of the so-called ''Bc'' or small pueblos to the large town sites and the reasons for the abandonment of the canyon in the twelfth century (e.g., Bannister 1965; Bryan 1941, 1954; Hawley 1934; Hewett 1936; Judd 1954; 1959, 1964; Kelley 1966; Kelley and Kelley 1975; Kluckhohn and Reiter 1939; Reyman 1971; Vivian 1970). Several scholars have attempted to study these issues, in part, based on historic Pueblo data (e.g., Judd 1954; 1964; Titiev 1944; Vivian 1970; cf. Cushing et al. 1922; Reyman 1971, 1976a).

The major breakup of Chaco Canyon towns in the mid-twelfth century was probably caused by several factors. These continually fed back into the system to worsen an already deteriorating situation; eventually, Chacoan culture collapsed. Included among these factors are mismanagement of land resources, especially the overexploitation of the mesa-top vegetation, population expansion, cyclical arroyo-cutting, withdrawal of the Mexican *trocadores* and their economic support,[17] and intra- and interpueblo disputes, probably over resource allocations.

Space limitations prohibit consideration of all these factors. Thus, discussion is restricted to those aspects discussed earlier in this paper, namely, the interplay of environmental conditions and priestly behavior. Titiev (1944:98) suggests that:

> . . . the phenomena of Pueblo mobility and Pueblo decline are interrelated, that both are caused by the same sets of factors, and that they are more fruitfully studied as sociological rather than ecological problems.

I disagree with Titiev's assessment of the situation. Any social system must operate in response to its envirnoment, and an ecological study, in part, is concerned with the nature of this response, with the process of interaction. For example, Bradfield (1971) demonstrates that Titiev overlooked the significance of the 1892—1904 drought as a basic factor in the breakup of Old Oraibi.

The ecological perspective necessarily includes consideration of sociological problems. It is my contention that, in some ways the abandonment of Chaco Canyon followed the process involved in the disintegration of several historic pueblos, of which Old Oraibi is the best known example. I would also argue that the Chaco situation involved the sorts of priest—village—environment problems discussed earlier in this paper. It is toward the demonstration of this that testable hypotheses have been generated from the Pueblo ethnographic data, data which have already been considered above at some length.

Special considerations permit consideration of but two of these hypotheses. Current research (Reyman ms.), when completed, will provide a fuller understanding of the problems involved and will include the actual testing of the ideas mentioned here.

The first hypothesis is that, as the ecological conditions at Chaco Canyon and the surrounding environs worsened, the priests increased their efforts to regain control of situation. These efforts, in turn, affected the behavior of the Chacoan peoples, as reflected in the materials found at sites in the canyon. Thus, the test implications for this hypothesis would include the following archaeological data, in addition to evidence for environmental deterioration, *per se* (cf. Bradfield 1971; Bryan 1941, 1954). All of the activities listed below are, to one degree or another, directed by Pueblo priests.

1) Proliferation of astronomically aligned architectural features, most notably to intermediate points in the solar year (e.g., equinoctial sunrise and sunset, zenith transit of the sun), to the lunar "standstills," and to the heliacal rise/set position of additional bright stars along the ecliptic.
2) Sudden and widespread refurbishing of existing ceremonial structures, particularly those used for communal or interpuebloan rituals.
3) Subsequent expansion of existing water control systems and the concomitant development of new ones.
4) Increased utilization of outlying areas and more marginal farming sites, and the establishment of small, chronologically late house units in close proximity to these areas.
5) Increased utilization of nonlocal plant and animal resources, as reflected in trash remains at the major Chaco towns. This would probably be coupled with marked changes in the remains of local foodstuffs, including the gradual(?) disappearance of those local flora and fauna most sensitive to adverse changes in the local environment.
6) A short-term increase, followed by a decrease, in the number of contemporaneously used food storage rooms and storage facilities (e.g., bins, sub-floor pits).
7) Expansion of the interpueblo communication system, specifically in terms of those sites with possible significance as signalling stations or as checkpoints along trade routes (e.g., Kin Ya's, Tsin Kletzin).
8) Marked increases in the production of trade goods, presumably to be exchanged for food or, perhaps, for nonindigenous items such as macaw feathers which were thought to be ceremonially necessary for food production to be successful.[18]

Although incomplete, the current research (Reyman ms.) has provided some preliminary results which appear to confirm items 1, 2, 4, 7, and 8. It should be noted that other test implications can surely be suggested.

If the environmental conditions improved, it would have appeared that the priests had regained control. Consequently, one would expect to see the situation stabilize and for this stabilization to be followed, possibly, by a period of cultural advancement coupled with population growth. However, if one assumes that the priests' efforts to regain control failed, and that the entire situation worsened, as apparently happened at Chao in the early twelfth century, then one can argue for the decline of priestly power followed by the beginnings of village fragmentation. Here, again, the Hopi materials provide important data relative to the prehistoric Chacoan Anasazi (see, especially, Bradfield [1971] and Titiev [1938, 1944].

The second hypothesis is that the disintegration of the Chaco towns followed a process similar to that involved in the decline of Old Oraibi. A number of test implications can be specified for which one would expect to find confirmation in the archaeological record.[19] The issue of arroyo-cutting has already been resolved at Chaco Canyon (Bryan 1941, 1954). Thus, just prior to the abandonment of the canyon we would expect to find:

1) A further increase in the number of astronomically aligned architectural features, both in the towns and on the surrounding mesa tops, these dating to the end of the main occupation, *c.* A.D. 1150. These alignments, however, would not be as regularly patterned as the earlier ones, i.e., they would appear to represent an attempt to incorporate all observed data regardless of their importance or relationship to each other.
2) A sudden abandonment of large sections of existing towns, followed by
3) Increased occupation of outliers and the construction of new outliers
4) The incorporation into these outliers of astronomically aligned building features, but such that the total configuration represents a haphazard and very imcomplete calendrical system in comparison with the earlier systems at the major Chaco towns (Moenkopi and Hotevilla are specific examples used here as ethnographic models, especially their histories following the collapse of Old Oraibi).

5) A sudden collapse in the maintenance of the water control systems within the canyon and in the surrounding mesa tops, coupled with
6) The apparently simultaneous construction of water control systems at the outliers, these however—initially—of lesser architectural quality and complexity.
7) Significant decreases in the amounts and varieties of trade goods, both imported materials and items manufactured for export.

As before, this list of test implications is not exhaustive. There are almost certainly room occupation and utilization date which also reflect this disintegration, e.g., the abandonment of most food storage facilities, a marked decrease in trash deposition, etc. However, these data are are still being analyzed in terms of this hypothesis,[20] and I hope to report further on this and on other related issues in the future (Reyman ms.). Finally, any one or even several of the test implications listed here might also serve as test implications for other hypotheses. It is the combination of these which is significant in terms of my specific hypothesis and the entire issue of priestly power and Pueblo behavior.

CONCLUSION

Archaeologists continually seek fresh approaches to the study of their data, the better to explain human behavior. The ethnographic literature is a major source for information on historic Pueblo behavior and the people who are the descendants of the prehistoric Anasazi. This literature provides empirical data for the formulation of testable hypotheses relating to these groups. The preceding discussion demonstrates that the priests have the power to regulate much of Pueblo socioeconomic and religious behavior. The maintenance and expansion of this priestly power rest, in turn, on the priests' abilities (competence) and favorable environmental conditions. Errors made by the priests upset village life; when coupled with adverse climatic conditions, even relatively short-term ones, such errors can rend, irreparably, the fabric of Pueblo society. All of this suggests that the predictive dimension of priestly power must be considered and utilized; it provides a valuable perspective from which to study the ethnographic situation and Anasazi archaeological record.

NOTES

1) For instance, among the Hopi, the lunar months are reckoned and named, in part, on the basis of changes in the flora and fauna. The blooming of the prickly pear catus (*Opuntia* sp.) in March, because it signals the availability of this plant for food during a period when food is otherwise relatively scarce, is important to the Hopi; *ü̈shе müiya-uh,* "prickly pear moon" (Fewkes 1892; cf. Beaglehole 1937' Forde 1931; Parsons 1933; Stephen 1936) is the name for March.
2. Furthermore, I have examined the probable prehistoric Mexican origin for much of Pueblo astronomy, ceremonialism, and other complexes, as these are known from the ethnographic literature. And I have also considered the superimpostion of the various Mexican astronomical practices on the simpler, indigenous Ansazi astronomy (Reyman 1971, 1976b, 1978). As noted in these earlier reports, one conclusion of this research is that the statistically greater-than-expected correspondance between the Mexican and Puebloan astronomical systems and accompanying socioreligious complexes supports the hypothesis that Pueblo culture developed, to a significant degree, in response to Mexican influence and economic exploitation (cf. DiPeso 1968; Kelley and Kelley 1975). In short, as I have argued for some time, Mexico and the Southwest constituted an Interaction Sphere in which the respective groups existed in symbiotic relationships. For the Anasazi, this relationship developed mainly after A.D. 700-800, although there were earlier contacts between the

two areas (Kelley and Kelley 1975; Reyman 1971). Prehistorically, then, the northern frontier of Mesoamerica lay just north of the Four Corners region.

3. The term "priest" is used throughout this paper to refer to the head priest at a village, e.g., the *cacique* (eastern Pueblos) or *p̂ekwin* (Zuñi), or to the priest in charge of making and recording astronomical observations, e.g., *masewi* (Santa Ana, only) or *ta´wa moñwi* (Hopi).
4.) Some of the variation may also be due to differential contacts with prehistoric Mexican traders—*trocadores* (see note 2, above, and Reyman 1971, 1976b, 1978).
5. Except at Santa Ana where the *masewi* (War Chief) makes the solar observations (White 1942). Santa Ana is unique among the Keres in assigning this duty to the *mesewi*.
6. *Cacique,* of course, is the Spanish term for the person who is generally considered to be the Town Chief (as opposed to the War Chief or outside chief). The native terms for this person are still used in the individual pueblos, although at Cochití the people commonly use an abbreviated version of the Spanish term—*"ka´sīk"* (Lange 1959).
7. Some Pueblos such as Zia and Taos consider the moon to be a male, while others like Islata and the Tewa believe it to be a female (Parsons 1939).
8. Lange's (1959) data indicate that the Cochití recognize months as lunar periods, but neither count nor name these periods in their traditional native astronomy, as we now understand the system.
9. There are few data on Laguna and Acoma, the other two western Pueblos. Astronomical observations and practices at Laguna seem to have lapsed some time ago (Parsons 1939). The data from Acoma are fragmentary (Parsons 1939) but appear to indicate that the system is about midway in complexity between the astronomical systems of the eastern Pueblos and that of Zuñi. This is consistent with the geographical location of Acoma, its history, and what we know about it in comparison to other Pueblos in terms of kinship, social organization, etc. (e.g., Eggan 1950; Fox 1967).
10. This is the generally accepted approximate date for the founding of Old Oraibi. Other locales in the Southwest such as Chaco Canyon, Mesa Verde, and the Wupatki area also contain evidence for solar calendars during this same general time period (Reyman 1971, 1976a, ms.).
11. The accuracy of these calendars and their effectiveness in terms of the subsistence systems should be obvious: The Hopi have inhabited many of their villages and maintained the integrity of their economic system for hundreds of years. In fact, Old Oraibi has been occupied continuously since perhaps as early as *c.* A.D. 900-1000. It appears likely (Bradfield 1971) that the 1892—1904 drought and other adverse climate conditions were the basic causes of the splitting of Old Oraibi in 1906.
12. It is not hard to understand how this might have happened. Hotevilla was settled mainly by people from Old Oraibi. In moving to Hotevilla, the priests probably lost sight of, or saw from a different perspective, many of the topographic features on which they relied for calendrical calculations. Furthermore, due to the split, some of the priests and the knowledge they possessed, including techniques of astronomical observation and recording, were probably lost.
13. Using Goldstine's (1973) data, a check was made for the coincidence of the winter solstice and the full moon. Several different results were obtained which varied depending upon the constants used in the calculations and especially as one changed the allowable margin of error, in days, used in working the formulae.

    1) Assuming that the date of the winter solstice is 21 December, but allowing ± 1 day to cover for those years when the solstice occurs on 20 or 22 December, the winter solstice coincides with the full moon once every 11 years then 8 years, then 11 years, etc. for up to 106 years; then there is a shift in coincidence to once in every 19 years for 247 years, then a shift back to the 11/8 pattern for 87 years,

then back to the 19 year interval, and so forth. The shifts occur mainly because of the rounding problem.

2) If we use the 21 December date, but allows ± days in thge calculations as a control for the shifting solstice date *plus* observational problems which may arise due to bad weather, then the pattern of coincidence for the two events usually follows an 8,3,8 years sequence within the 19 year cycle, then shifts to an 11,8 years pattern, then back to the 8,3,8 year sequence. The segments in this series can last as long as 209 years.

3) Using the 21 December date, but allowing for a ± of ► 2 days but ◄ 3 days, one finds that the frequency of coincidence follows an 8,3,5,3 year sequence for up to 266 years, then shifts to the 8,3,8 year pattern, and then shifts back again.

4) Combining all of the above possibilities, i.e., using the 21 December date with an allowable error 0 to ± 2.99 + days, the frequency of coincidence between the winter solstice and the full moon can occur as often as once in every 3 years—5 years—3 years—3 years—5 years in the 19 year cycle for up to 57 years (see Table 1); then the number of years between the cases of coincidence begins to lengthen.

Finally, the number of years in the various year counts cited above (e.g., 106, 247, 266, 87) is also variable, again largely because of the rounding problem. This situation obviously complicates further the efforts of the priests to achieve accurate astronomical calculations (for additional discussion of solar and lunar cycles, see the note by Born at the end of this paper).

14. For some ceremonies, the ''long'' form may last up to 10 days, while the ''short'' form may be held for only a day or two.
15. It has been suggested (John Fritz, personal communication, 1-22-79) that if nature is constant, then variation has to be explained by human error. Therefore, priestly error is a metaphor for human error in general. The point is well taken but needs clarification. In the Pueblo cosmology, gods control the weather and provide other benefits for humans. To secure good weather and these other benefits requires that the Pueblos obtain the gods' help through proper ritual. Bad weather, crop failure, poor hunts, etc. occur because the proper ritual and accompanying correct behavior (e.g., observance of food and sexual taboos) are not followed. Thus, good weather and other favorable conditions are considered to be constants; variations in them are seen as dependent upon human behavior with adversity due to human error. Since the priests are in charge of ritual, the error is generally seen as theirs. They system is reinforced and persists because the desired results follow often enough from the prescribed (and presumably correct) ritual behavior. Pueblo reasoning, in the situation, is obviously circular; but it is consistent with their belief system and ''explains'' the operations of the cosmos as they understand them. This is an excellent example of ''the logic of the irrational'' (Spiro 1966).
16. The lack of centralized authority, especially at Hopi and Zuni but also apparent elsewhere, may be a relatively recent development. It is not so apparent prehistorically. At Chaco Canyon, for example, the existence of large ''ceremonial'' structures—the so-called ''isolated Great Kivas''—like Kin Nahasbas and Casa Rinconada suggests the development of inter-pueblo political control, perhaps externally imposed (cf. Frisbie 1978; Grebinger 1973; Kelley 1966; Kelley and Kelley 1975; Reyman 1971, 1978).
17. For a further discussion of this see Kelley (1966), Kelley and Kelley (1975), and Reyman (1971).
18. The issue of ritual paraphernalia needed by the Pueblos to ensure the success of their ceremonies is further discussed by Parsons (1939), Reyman (1971), and Stephen (1936), among others.
19. Obviously, failure to satisfy these test implications invalidates the hypothesis, i.e., that the abandoment of Chaco Canyon did not follow the Hopi example.

20. I have excluded here any consideration of the possibility that the Chacoan decline and abandonment were partially caused by changes in the interrelationship of the Chaco peoples with Mexican *trocadores.* Alternatively, the Chacoan decline may have precipitated changes in Mexico, especially as Mexican - Southwestern trade networks were disrupted forcing the Mexicans to look elsewhere for supplies of turquoise and other materials. In fact, I think that the Chacoan decline was hastened by a breakdown in economic relations with northern Mexican cultures (Reyman 1971; cf. Kelley 1966; Kelley and Kelley 1975).
21. The help provided by my research assistants—Sandra Faikus, Gary Urton, Rose Schilt, and Anne Weirich—is gratefully acknowledged. John M. Fritz provided a number of critical and useful comments. However, I am solely responsible for the contents of this paper and for any errors in fact or interpretation. Thanks also to Dr. Harold J. Born of the ISU Physics Department who helped with some of the astronomical data and whose note on solar and lunar cycles follows. Research funds for this work were provided by National Science Foundation grants GS-40410 and BNS77-08070 and by Illinois State University.

A NOTE ON SOLAR AND LUNAR CYCLES

BY
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Using 1 tropical year = 365.242199 solar days and 1 lunar cycle = 29.530588 solar days, one gets the 3, 8, 11, and 19 year coincidence cycles from the following figures.

3 years	= 1095.7266 days
37 lunar cycles	= 1092.6318 days
8 years	= 2921.938 days
99 lunar cycles	= 2923.528 days
11 years	= 4017.664 days
136 lunar cycles	= 4016.160 days
19 years	= 6939.602 days
235 lunar cycles	= 6939.688 days

The last ones are so close that, assuming one allows a 2-day error, it would take 8488 years for the 19 year cycle to be in error (assuming that one starts with an *exact* coincidence; if one starts with the 2-day error in the opposite direction, it would take about 17000 years). It is for this reason that the "repeat cycles" appear in the data, e.g., 8,8,3,8,11, etc. These must add up to 19 years, except for once every 4244 years or so (the amount of time needed for a 1-day error to creep in). All of the above are mean figures and have not been corrected for perturbation, etc.

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SOCIAL RANKING IN CHACO CANYON, NEW MEXICO: A MESOAMERICAN RECONSTRUCTION

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ABSTRACT

Models for social ranking, i.e., chiefdom-like organization, have been presented in print by several individuals to account for what has been termed ''the Chacoan phenomenon.'' However, the models do not take account of Mesoamerican derived features that are readily apparent in the area. The present paper utilizes both internal and external causative factors with the latter acting as a catalyst on the former. the sequencing and patterning of cultural events offered by this interpretation appear to be congruent with the archaeological data currently available.

INTRODUCTION

I would like to begin with a statement which has very little obvious bearing on the present topic—until one grasps its true significance. In 1927 Earl Morris published a paper entitled, ''The Beginnings of Pottery Making in the San Juan: Unfired Proto-types and the Wares of the Earliest Ceramic Period.'' It is a classic example of the isolationist view of the development of Basketmaker-Pueblo ceramics. In the fifty-one intervening years since its publication numerous data have been presented to provide incontrovertible evidence for the Mesoamerican-derived origin of ceramics; this is now accepted as a ''given.''

This ''thing''—Mesoamerican influence in the Southwest—has had, in actuality, a long and varied history. Some of the first anthropologists working in the 19th century, including particularly Fewkes and Bandelier, noted numerous parallels; then, with but few exceptions, a long hiatus ensured. It was not until the mid-1940s that attention was again focused on the problem by Brew (1944), Brand (1944), Beals (1944a, 1944b), Kelly (1944), and Haury (1944, 1945). The 1950s witnessed great gains, including the concept of the Greater Southwest (Kirchoff 1954) and Ferdon's (1955) pioneering work with Chacoan-Mesoamerican parallels, particularly architectural ones. By the 1960s some of the old guard were faltering; Mesoamerican influence in the Southwest became more widely accepted, hotly debated, and more avidly sought out, both north and south of the border (Dutton) 1964, Kelley 1966, Stanikslawski 1966, Haury 1967, and DiPeso 1968a, 1968b). Differing types of diffusion were suggested by Schroeder (1965, 1966)—these initial unregulated diffusion followed by pattern diffusion: the latter required physical presence (i.e., migration) of Mesoamerican peoples. More recently the Kelleys (1975) presented a comparable, but more comprehensive model for the Anasazi utilizing the concept of ''soft'' and ''hard'' diffusion. The latter employs the *trocadores* or puchteca (i.e., long distance traders) as catalyst.

Coupled with the above has been a growing, far clearer understanding of cultural events in northwestern Mexico; what was formerly largely *terra incognita* is yielding a data base which relates directly to cultural events in the American Southwest. In point of fact, there is little, if any, doubt in the minds of many of us that these events provide the impetus for all major culture change in the area. The work of DiPeso (1974) at Casas Grandes and elsewhere, as well as that of Kelley (1966, 1971, 1974) and Kelley and Kelley (1966, 1971; see also 1975) concerning Chalchihuites culture (especially their recent work at Alta Vista), and the research of numerous others (many of whom are Kelley students) must be taken into account when attempting to interpret that which has occurred in the American Southwest. There was, in actuality, *nothing* to stop Mesoamerican northward expansion except the realization on the part of the Mesoamericans, themselves, that it was pointless to go further. It is obvious that the greater the distance from its center, the more attenuated form a manifestation will reveal; this can be domonstrated with the series of trading/exploitation centers moving northward from the Mesoamerican hearth area. Thus, if Chaco Canyon

and its environs are properly placed as the northernmost in this long chain, one should expect considerable variation and latitude from the original source.

If, then, we can attempt to envision this cultural infusion in the Chaco Basin, what might we expect? This paper provides a glimpse into one aspect, namely socio-religious control. Before providing a model which I feel offers great congruity, previous attempts to delineate the social system must be reviewed and evaluated.

MODELS OF SOCIO-CULTURAL LEVELS OF INTEGRATION AT CHACO CANYON

The interpretation of Chaco Canyon as a major center of Puebloan culture begins with initial scientific work prior to the turn of the century by the Hyde Expedition under the direction of George Pepper (1895, 1905, 1906, 1909, 1920). Through time, attempts to delineate social organization have relied heavily upon analogies with the modern pueblos, drawing data from ethnohistoric and the ethnographic present. The last major work of this nature was by Vivian (1970a, 1970b) wherein a dual division (i.e., moiety system) is presented as representative of ''towns'' featuring large communal structures, great kivas water control systems and other advanced features. ''Villages'' were organized according to principles of localized corporate lineages. Vivian, it should be noted, using multiple working hypotheses found an essentially negative correlation for *puchteca* or *trocadores* influence in Chaco Canyon.

In 1972 I presented a paper at the Society for American Archaeology annual meeting entitled, ''The Chacoan Interaction Sphere'' where in the puchteca model was suggested as a viable hypothesis to explain developments in Chaco Canyon proper, as well as a means of incorporating the numerous satellite sites (Frisbie 1972). Although not developed at that time, in the concluding section I stated that the satellites were integrated closely to the Chacoan center. Further, I noted that indications pointed to the fact that this would, of necessity, require centralized control over a vast network having a more complex level of social integration than that exemplified by the pueblos of the modern or historic period. (At present I would temper the inclusion of ''historic'' because I am not aware of the interaction of and between the ''Seven Cities of Cibola'' (really six Zuñi villages: Hawikuh, Kiakima, Kechipawan, Halona, Matsakya and Kwa ina). Was there, for example, a hierarchical arrangement of some kind?[1] I wonder also about the Tewa area and Tanoan Pueblos in the Rio Grande as well as others. Certainly the possibility exists; however, it would not have been, in my opinion, of the same magnitude as that found in the Chacoan phenomenon. This, then, raises the question: immediately following the Chacoan Interaction Sphere ca. A.D. 1138, or at some later date? Do remnants of such a system remain?[2]

A third construct, by Grebinger (1973), proposes a ranked society of relatively pristine type which is based in Fried's (1967:111) model. Grebinger argues that differential agricultural productivity is at the base. He sees those favored with highly productive lands, the result of summer thundershowers and catchment systems, undergoing change and forming towns with status differentiation, redistribution, and lastly, task and craft specialization. He notes, too, that following this development of ranked society, water control systems were instituted—the probable result of population expansion and ''increasingly heavy thunderstorms.'' Mesoamerican influence is not considered.

The fourth model presented by Judge (1976) as a trial formulation utilizes a processual approach which is ecologically based and evolutionary in nature. He suggests that differential adaptation and utilization of available resources within the ecosystem gave rise to reciprocal kin-based exchange in the Basketmaker-Early Pueblo period. This, in essence, provided necessary balance for the system to operate. Early in the 10th century, or slightly before, the reciprocal exchange became more formalized so that what had been kin-based was transformed into an ''incipient redistributive network'' with Chaco Canyon as its natural center. Here, storage and manufacture of items are logical and with them craft specialization begins, particularly work in turquoise. The next step, termed the Bonito phase which occurred during the 11th century, is an obvious one; a full

fledged, highly formalized Chacoan redistribution network featuring full-time administrators, craft specialists, et al., all of whom were supported by the system. The satellite sites are incorporated at this time as well. As described, this model is derived from events occuring *within* the Chaco Basin. Judge develops the ecological basis for the model beautifully, so that it appears to be a most logical construct; he pays lip service to possible "outside" influence ". . . imposed on the Chacoan population . . . by a presumably more advanced people" (Ibid.:9). Should his model not be supportable, one might then consider the alternative, namely one based on the influx of Mesoamericans.

"THE MESOAMERICAN DERIVED MODEL"

To date no one has been able to demonstrate Mesoamerican interpretation conclusively though many have tried to show contact of consideration magnitude. These include Ferdon (1955), Schroeder (1966), DiPeso (1968a, 1968b; see also 1974), Kelley (1966), Frisbie 1971, 1972), Reyman (1971), the Kelleys (1975), and others. The most recent statement from the Chaco Center provides a summary of Mesoamerican traits as they relate to a complex redistributive network (Lister 1978); however, they are not considered sufficient either to prove or disprove *actual* Mesoamerican contact (Ibid.: 239-240).

To present my case I have chosen to argue using a cybernetic model developed by Peebles and Kus (1977) as proposed in "Some Archaeological Correlates of Ranked Societies." They present five correlates, leaving *aside* redistribution and ecological specialization as necessary and sufficient determinants of ranked societies, commonly called chiefdoms. My ultimate objective, of course, is to demonstrate as conclusively as possible that the "Chacoan phenomenon" is Mesoamerican derived, based on the *trocadores* or *puchteca* model. In the process, I hope to show, also conclusively, that we are, in fact dealing with a level of socio-cultural integration synonymous with a ranked society.

Correlate 1: There should be clear evidence of nonvolitional ascribed ranking of persons discernible in the burial record.

High status burials occur at the largest Chacoan ruin, Pueblo Bonito, and undoubtedly at Peñasco Blanco (although these latter were plundered and lack documentation in the literature, except for casual mention); others occur at satellite sites including Aztec Ruin and the Escalante Site (Mesa Verde area). All are characterized by lavish grave furnishings, often in astonishing quantities—for example, 50,000 beads of shell, turquoise, and other materials with one burial at Aztec Ruin. Other frequently occurring items include mosaic inlays, turquoise incrusted objects, flutes and whistles, canes of office or ceremonial staffs, conch shell trumpets, jet/lignite pendants (sometimes in effigy form), abalone shell objects, and a hosts of others. Many of these items typologically originate in Mesoamerica and occur along the corridor between the two areas. It should be noted, too, that extended burials, another Mesoamerican derived trait, take precedence beginning ca. A.D. 1000 (Stanislawski 1963). Among these burials staging or sequencing may be cited as an additional trait originating in Mesoamerica; of particular interest are two burials, including the richest of all, which were entombed in a crypt topped by a hewn plank cover in which a sipapu-like opening was made, again Mesoamerican *sin duda!* These occur in Room 33 at Pueblo Bonito. It is also possible that burials above prepared crypts, when they occur, could be sacrificial victims meant to accompany the dead. Other specific, exceedingly specific to be more precise, data could be cited pertaining to the burials of high status individuals; referral is made to the original reports, as well as to two recent papers by Reyman (1978) and myself (Frisbie 1978:213-215).

Correlate 2: Hierarchy of settlement types and sizes should reflect their position in the regulatory and ritual network.

As noted previously it is the large Chacoan "towns" and associated great kivas, as well as other structures which characterize the Chacoan phenomenon within the canyon and at satellites. Interestingly, the largest, Pueblo Bonito, has produced the richest burials. Further, it can be con-

clusively demonstrated that high ranking individuals occupied three isolatable, contiguous blocks of 25-35 rooms in the Old Bonitian section. Within these blocks the richest remains are within the central section, flanked on either side by slightly lesser ones. Other conclusive data support the fact that exotic Mesoamerican derived items of material culture occur in these sections—for example, copper bells, macaws, conch shell trumpets, pyrite mirrors, etc. Exceptions include kivas and trash deposits; elsewhere such items are non-existent or exceedingly rare.

Architectural features having *no* antecedents in the American Southwest[3] appear in profusion: from rubble core faced masonry to construct multiple stories, to overall planning, with specific features and structures such as square column collonaded galleries, stairways, towers/observatories, platform mounds, etc. Each of these is congruent with Mesoamerican architecture both prior to and of the period of time in question (i.e. 11th century).

Correlate 3: All settlements should be located in areas which assure a high degree of local subsistence efficiency.

I believe that all major Chacoan sites, as well as the 30 some satellites (unless serving in the capacity of "way stations") were carefully located to take advantage of large tracts of arable land. These often feature special topography such as catchment basins, mouth of canyon, and others. Satellite site selection incorporated such factors as a supporting local population with whom previous contact had been of long standing. An awareness of exploitable natural resources within these locations undoubtedly received consideration as well. In other words, specific criteria were utilized rather than haphazard, random selection for the location of all satellites. I believe these are isolatable data. Of these satellite areas, the Zuñi region continues to be occupied and holds a unique position with respect to Chaco for this region. As an aside, there should be little, if any doubt, that present day Zuñi carry some genetic material attributable to Chaco Canyon peoples, as well as some cultural features. Interestingly, Zuñi has been characterized as having the most complex social system of the extant pueblos (Pandey 1978 and others).

Correlate 4: There should be organized productive activities which transcend the basic household group such as: a. monumental architecture and b. organized part-time craft specialization with intersocietal trade.

Without question Chacoans produced architectural structures which comply with this correlate. The ruins themselves are large and master planned, requiring organized labor. It is possible to utilize tree ring dates to show specific construction periods of major importance at specific sites, even to the point of movement in construction work from one site to another (Bannister 1964:200-201). Great kivas further exemplify the correlate, as do water control systems (Vivian 1970a, 1970b), signaling systems (Hayes and Windes 1975), and the more than 250 miles of roads which are up to 9 meters wide and feature such additional features as rock cut stairways to negotiate cliff faces (Lyons and Hitchcock 1977, and elsewhere). The roads lead to satellite sites which, themselves, all appear to have been built during a relatively short period of time (ca. A.D. 1050). This period is, of course, at the very height of Chacoan control and domination.

Organized part-time craft specialization has been noted to center on the working of turquoise from raw into finished form as evidenced by the tremendous number of turquoise artifacts recovered with hundreds of thousands coming from Pueblo Bonito alone. Much more was probably "exported" to the south than remained for local high ranking administrators. Although from a slightly earlier period, Weigand, Harbottle and Sayre (1977) reported 50% of the turquoise tested from the Guadiana Branch of Chalchihuites Culture (A.D. 200-800) originated at the Cerrillos Mines of New Mexico. Certainly much of that employed by Chacoan artisans had a similar origin. Additionally, work in a variety of other media is noteworthy; included here are shell, jet, lignite, wood, and bone.

Warren's (1976) ceramic data indicate very little pottery was made in Chaco Canyon proper; rather, up to 80% was of non-local manufacture as evidenced by detailed temper studies which indicate manufacturing sites occur at distances of from 15 to 70 miles. Judge (1976:9) notes a

similar situation for much of the chipped and ground stone artifact assemblage. Thus, intersocietal movement of goods is present and of considerable importance for both exotic and non-exotic items. Again I would reiterate, I doubt very strongly that exotic items reached the common individual for his or her personal use to any appreciable extent, these materials being reserved for status holding societal members. It is possible they could have been considered *teshkwi* (taboo) for low status holders.

Correlate 5: "There should be a correlation between those elements of the cultural system's environment which are of a frequency, amplitude and duration to be dealt with which are at least predictable and evidence society-wide organizational activity to buffer or otherwise deal with these perturbations."

At ca. A.D. 1050 with the satellite network in full operation, there is little doubt all of the perturbations—problems with rainfall, first-last frost, floods, and so forth, could be met because of the regional and environmental diversity of satellite locations. A very obvious diversification was created in order to provide a mixed strategy of regional exploitation. Further, storage and distribution of foodstuffs in times of need (as well as for feasting) were probably integral parts of the system. The ethnographic present, and to some extent more recent data indicate the cacique or village religious leader (i.e., "mother") had/has in his charge quantities of foodstuffs for this purpose.

CONCLUSIONS

As presented, I cannot visualize anyone denying ranked society status to the "Chacoan phenomenon"; the data herein are ordered somewhat differently, but I believe quite in line with Judge's "Complex Cultural Ecosystem" which arrives at the same basic conclusion. We are, therefore, left with consideration of the *trocadores* or *puchteca* question. Were they or were they not integrally involved with the creation of the system? Data from Mesoamerica place them within close proximity to the border, and thence southward to the hearth area. Since a highly desirable, exploitable material, namely turquoise, was present in quantity, the impetus would definitely be present for such an undertaking; exploitation was, after all, one of the very reasons why *trocadores* existed, and as previously stated, nothing stood in their way. To my way of thinking they had a great deal to offer—a new ceremonial system including introduction of the concept of priesthood, a more assured way of life through the introduction of more advanced varieties of maize and other plants—coupled with calendrics based on astronomical observations as well as other features. Undoubtedly these exploiters had had previous contact with their hosts, positive contacts to be more precise. Although the turquoise deposits were at a considerable distance (in excess of 100 miles), the Chaco region was selected because a system was already developed on which they could easily superimpose their own, more advanced one. It is highly probable that the movement was outwardly manifest as a religious conversion experience and throughout its short history (ca. 150 yrs.) religion remained paramount, as it has to the present time in puebloan culture.

Even though one cannot, in all fairness, state great quantities of Mesoamerican artifacts appear within Chaco Canyon and its environs, I personally do not feel Haury's off the cuff statement, "You could put all of the artifacts from Mesoamerica on the back of one pochteca," need concern us. Such items were *not* for the masses. They were special insignia of the high ranking officials and most were probably taken back to whence they had come by retainers following the collapse of the "Chacoan phenomenon" ca. A.D. 1138. Those remaining had either been lost, ceremonially deposited, placed in the ground to become integral parts of the burial record, discarded once their utility had ceased, or had died as in the case of macaws.

With respect to the *trocadores* or *puchteca* we have two bodies of data with which to deal. The first of these relates to the burial record. Without question, particularly reminiscent to those south of the border. The accompanying artifacts, likewise, manifest great similarity. It is unfortunate that recent excavations have not revealed additional finds in Chaco Canyon; there are probably some to be found and their whereabouts should be ascertainable.

As a corollary to the artifacts which accompany high status burials are those which are of known Mesoamerican derivation: conch shell trumpets, pyrite mirrors, pseudo-cloisonne, a pottery stamp, and others. These, too, are important and without antecedents in the Chacoan area.

Although some researchers pubnaciously cling to the necessity for new field research on which to base interpretations, there are those of us who feel considerable merit can derive from reanalysis and interpretation of that which is currently extant. This is particularly true for the Chaco because many of the data relating to that which has been termed the ''Chacoan phenomenon'' derive from early sources in the annals of Southwestern prehistory (Schwartz n.d.). To date, one of the most outstanding examples relates to the reanalysis of ceramics, especially figurines. Washburn (1978) has clearly demonstrated that a sandal type, painted on the foot of one such vessel fragment from Room 329, Pueblo Bonito, is not otherwise found in the Southwest, but instead, is like those worn by Post Classic *puchteca* and lapidary deities in the Mexican hearth area. That this fragment occurred as a grave good in one of the high status burial areas of the pueblo is significant as well. This ''bit'' of information is profoundly important and indicates the necessity for continued gleaming of the previously excavated materials from the archaeological record.

The final data relate to the complex of architectural features which arise with the full-blown Chacoan cultural expression. Why should all of these appear at a particular point in time, several hundred miles from their closest counterpart? A few perhaps, but *all* of them, not to mention all of the other traits? The total constellation is, and should be, mind boggling. I can see no other explanation than that which is proposed herein. I cannot help but state that just as Morris clung to the isolationist view for the development of ceramics at a time when this was in vogue, those who have difficulty accepting not only Mesoamerican influence but also Mesoamerican influx at Chaco will ultimately recognize and accept the inevitable: Mesoamericans were involved; they ordered, conducted, and ultimately withdrew—but in the process, left an indelible mark which is still discernible in some manifestations of extant pueblo culture.

NOTES

1. Historical documentation indicates that the Zuñi fled to Towayallane during several periods of stress following the Spanish *entrada*. Ultimately all of the villages extant at contact coalesced at Halona or Itiwanna (Middle Place). This occurred in 1699. Precisely what internal mechanisms came into play to allow amalgamation are, of course, unknown; however, what ermerged has become part of the ethnographic present as recorded by numerous anthropologists. I believe it would be highly unlikely to expect each of the original villages to have had a full compliment of ceremonial officers; for example, the Pekwin or Sun Priest who was the most important of these, probably served all of the villages from Halona. This appears a highly logical construct since this pueblo was legendarily the first one settled in the area by the Zuñi, and likewise, represented the center of the world. The tight-knit interaction of the villages as revealed by ethnohistoric sources tend to add credence to this hypothesis as well. In summary, it would appear the original question posed deserves further consideration.
2. Comment provided by an anonymous symposium attendee, based on fieldwork at Taos, indicated definate remnants are present for the Tiwa with Taos assuming the major role. Further it was stated that staged burials of ceremonialists occur at this pueblo.
3. As indicated by a symposium attendee, the earliest rubble core masonry occurs in the Ackmen-Lowry area of southwestern Colorado; however, this does *not* compare with that found in Chacoan sites.

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THE MEXICAN CONNECTION: CYLINDER JARS FROM THE VALLEY OF OAXACA

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ABSTRACT

For many years the unusual nature of the large multistoried sites of the Pueblo III period in Chaco canyon and the rich array of jewelry and other artifacts found in these ruins has provoked many speculative explanations. The large amount of shell in both raw and finished jewelry form can perhaps be accounted for by positing activities of local traders venturing to the Pacific Coast. However, the presence of macaw burials and cooper bells—two items which undisputably are not native to and were not made in the American Southwest—must be accounted for by postulating some form of trade with/or foreign presence of populations from the higher civilization to the south. This paper presents an attempt to confront one body of yet unanalyzed data—cylinder jars—in an effort to more clearly specify the loci and type of Mesoamerican connections.

George Pepper was the first to formally excavate Pueblo Bonito in the late 1890's (Pepper, 1920). The site was reexcavated by Judd in the 1920's (Judd, 1954). He concluded that there had been two populations living at the site. One, which he called the Old Bonitians, were the initial founders of the site and made Transitional, Early Hachure, and Solid decorated pottery styles. The second population, which he designated as the Late Bonitians, represented the ''eleventh-century immigrants'' who made Late Hachure, Chaco-San Juan, Mesa Verde and all-over corrugated wares. Judd suggested that the founders came from the southwestern Colorado area, citing the similarity between Mancos Black-on-white from Lowry Ruin and Transitional types from Old Bonitian rooms (Judd 1954:30). The Late Bonitians, however, were thought to Chaco from the Zuñi mountain region bringing their superior masonry techniques (Judd 1954;35).

A reexamination of the data, however, suggests that some of the occupational debris assigned by Judd to the Late Bonitians may not represent a Southwestern population at all, but rather a small group from Mexico. One way to demonstrate this possibility is through a detailed examination of the artifactual material associated with the bodies of these postulated foreigners. This paper will focus upon the cylinder jars which are found in association with these mass burials richly adorned with goods atypical of the Anasazi.

Symmetry analysis (Washburn, 1977) of the designs suggests that the designs are not derived from the antecedent Pueblo II Red Mesa Black-on-white design system based on the structure 1-200. Since similar abrupt design layout changes between Pueblo III and Pueblo IV Hopi area pottery designs have been attributed to Mesoamerican incursions (Brew, 1974), it was deemed viable to consider similar sources for these Chaco discontinuities. The context in which these unusual vessels were found will first be described and then their characteristics will be assessed.

The number of cylinder jars recovered from sites in the American Southwest is very small relative to other vessel forms. Other than those found at Bonito, Judd reports three plain polished red jars (1959, Plate 55 a,b,c) and one black-on-white jar (1959, Plate 24f), all of which were found in Room 15 of Pueblo Del Arroyo. (They had apparently fallen from the second story room above (Judd 1959;18). The 8.8 cm neck diameter and the 23.1 cm height for the black-on-white jar falls within the range for the Bonito decorated jars with four horizontal loop handles. In fact, the same design, consisting of columns of angled hatching in bands above and below the handles is found on a jar from Bonito, Room 28, except that in the Bonito jar the vertical columns of hatching are not divided into two bands above and below the four horizontal handles.

Two possible cylinder jar fragments have been recovered from the recent excavations at Pueblo Alto. However, the one black-on-white rim fragment which I examined August, 1978 had a diameter of 15 cm, which is larger then *any* of the 109 decorated or uindecorated jars I examined

from Pepper's excavations at Bonito. The mean diameter of these Bonito jars is 10.4 cm; none of the decorated jars are larger than 13.5 cm.

Roberts also reports finding two cylindrical vessels in the Piedra district (1930). One is decorated with vertical black lines, has holes near the rim for hanging, but is only 13.3 cm high and 10.5 cm in diameter. This height is below the average of 23.7 cm for the Bonito jars, but the neck diameter compares well with that for the Bonito jars. This jar was found in House C of the Group I unit in A village (1930, Plate 3), one of six rectangular houses arranged in a semicircle around a depression. Roberts does mention that such cylindrical jars are also found in highland Guatemala and recalls that the copper bells and macaws found in Bonito are evidence of Mesoamerican trade that presumably could have also been responsible for these vessels. However, he did not, as do Kelley and Kelley (1975) see much evidence for pre-Bonito phase traffic from Mexico and so he concluded:

> The evidence on intercourse between the areas is of so much later a date than that represented by the Piedra forms . . . that considering the problem as a whole it seems more likely that the cylindrical vases, like the making of pottery were an indigenous development in the San Juan culture area. (1930:107).

The other Piedra area cylindrical vessel (Roberts, 1930, Fig. 19n, Plate 33b) has a rectangular opening in the side and a closed flat neck and base area. It is 25.1 cm high with a base diameter of 10.5 cm and is decorated on the side opposite the "window" with two vertical rows of black triangles on a red slipped base. This possible "Feather Jar" (Fox, 1975) was found in the "Arrowmaker Burial," so-called because 22 projectile points and flaking tools as well as 21 ceramic vessels, including the feather jar, red ochre, paint pallets, and bones of a golden eagle were placed beside the flexed skeleton. The nature of the designs on the vessel, and the closed ends with a "window" on the side diffentiate this jar, although cylindrical, from all the other cylindrical Bonito forms and consequently it will not be cosidered further here.

The largest number of cylinder vessels were found by Pepper (1920) and Judd (1954) in Pueblo Bonito in situations atypical of Anasazi practices: two room blocks containing high status burials where the jars formed one of the many unusual grave goods, and one room with a cache of jars.

Associated with the 4 cylinder jars Pepper found in Room 32 were 33 decorated bowls, mugs and pitchers, a bird of hematite and turquoise inlay, a board with painted designs on both sides, a quiver with 81 arrows and, most importantly, a cache of 300-375 "ceremonial" crooks of four types placed upright in the northwest corner of the room. Kelley and Kelley have suggested that these are pochteca canes (1957:204). Scattered parts of a human burial suggest that prior to disturbance, this room was used as a burial chamber. Room 33 (Pepper, 1909) contained two elaborate sub-floor burials, and among the associated grave goods were a wide variety of pottery types including two cylinder jars and coiled cylindrical basket covered with 1214 pieces of turquoise mosaic. The basket itself contained 2150 disc-shaped turquoise beads, 152 turquoise pendants, 3317 shell beads and 68 shell pendants. Another cylindrical basket was covered with rows of strung turquoise and shell beads. Other rooms which contained cylinder jars or fragments of these jars were the debris in Rooms 39b and 52 and in association with a child's burial in Room 53. In this room the skull was accompanied by 4000 flat circular turquoise beads, 30 shell beads as well as the cylinder jar and several pitchers.

Judd found a similar unique array of luxury items in burials in four adjacent rooms in the west wing of Bonito: Rooms 320, 326, 329, 330. Room 320 was a burial chamber for 8 women and 2 children. Eight of the bodies had been disturbed; the two which remained intact were extended with heads facing East. Feather-cloth robes, cotton fabric, and yucca cordage were some of the grave goods. Room 326 was a burial chamber for 1 man, 9 women and 1 baby. Among the grave goods with these individuals are turquoise pendants at the throat, oval basket trays with deer humeri inside, many pottery vessels, clay models of bifurcated baskets, and coiled cylindrical baskets. Room 329 contained the interments of 16 women, 6 children and 1 man. Their bodies

had been badly disturbed, but left behind by the looters were 47 vessels, shell and turquoise pendants and jet and shell beads. Room 330 contained 13 men, 4 women and 6 children, but only burial # 10, a man with 28 projectile points between his knees, had not been disturbed. The remaining grave goods included 49 vessels.

Notable is the wide variety of types of the ceramic vessels. Judd comments: "Almost the whole range of Pueblo Bonito ceramic history is represented here (Room 326) (Judd 1954:192)." In this view the juxtaposition of Pueblo II with Pueblo III types has to be explained as heirlooms and later pots being deposited together. An alternative hypothesis is that these pots actually represent contemporaneously produced wares from a number of different areas.

Also notable is the small size of many of the vessels used as grave goods. Of the 17 bowls associated with the 23 persons buried in Room 330, 11 were very small. Likewise, 18 of the 26 bowls from the burials in Room 329 were between 2 and 4 inches in diameter. Judd suggests that these were children's toys but alternatively they may be miniatures produced as token offerings.

In two recent reviews of these burials their richness is contrasted with earlier burials from all three Southwestern prehistoric traditions as well as northwestern Mexico (Frisbie 1978), and it is suggested that the Bonito Room 32 and 33 burials as well as the Ridge Ruin "Magician" (McGregor 1943) represent pochteca (Reyman 1978). Reyman tallies the associated material and finds that it appears to be similar to paraphernalia pochteca might carry to trade, use or wear (1978:247). He concludes that it is the *degree* of elaboration that differentiates these burials from "typical" pueblo burials where the body may be accompanied by a pottery vessel or two, a piece of jewelry or a tool. Coastal shell or Cerrillos turquoise in these local burials may have been traded within Anasazi networks. However, many of the items associated with the high status burials definitely do not appear to be typical of local Anasazi practices or material assemblages and probably were obtained via an outside trade network.

Instead of being scattered on a "living floor" as if abandoned during use, in a storage room filled with grain, or accompanying a burial, 140 vessels were found stacked in Room 28. Although when discovered they were in disarray due to the weight of falling roof debris, 114 cylinder jars, 18 pitchers, and 8 bowls were originally neatly stacked in 3 piles with the bowls and pitchers at either end of a large pile of cylinder jars stacked on their sides. The presence of such a large number of vessels in one room in 3 distinct layered piles, as if awaiting use or shipment (the cylinders could not have been holding anything due to their position) has not been reported at any other Anasazi site. The fact that 75 sandstone jar covers accompanied these vessels suggests that they may have been intended for future use as storage containers and that Room 28 was merely a temporary depository.

Several pieces of evidence support this storage explanation. First, on the floor among the jars, bowls and pitchers were found 93 flat circular turquoise beads, 12 turquoise pendants, pieces of turquoise inlay and turquoise matrix and 400 shell beads. These items may have been stored in some of these vessels. Second, Judd interprets the condition of deposition in Room 28 as leaving the room suitable only for storage. He suggests that a considerable quantity of roof fall was already covering the floor when someone put the vessels in Room 28 near the doorway to Room 51a. "With only a 4-foot headway remaining, Room 28 obviously had little use thereafter except storage." (Judd 1954:24). Pepper apparently believed they were stacked in the middle of Room 28 prior to the fire in the second story room above Room 28 and that they were placed in that room so as to be readily available for use with the other ceremonial objects in adjacent Room 32. Among the other ceremonial material, Room 32 contained a group of over 300 ceremonial sticks stacked upright in the northwest corner. Pepper suggests that the cylinder vessels were used to hold these sticks (Pepper 1920:377) and that the loop handles were for attaching ceremonial feathers. (Pepper, 1920:121).

Examination of the early ethnographic literature which reports observations of late 19th century ceremonies does not support Pepper's hypothesized use of the cylinder jars. Photographs

taken by Dorsey and Voth at a series of Soyal ceremonials at Oraibi in the late 1890's show the ceremonial sticks either thrust into piles of sand on either side of the altar (Dorsey and Voth 1901, Plate XVIII) or held vertical in a cone of hardened clay (?) (see Dorsey and Voth 1902, Plate CXXV; Voth 1903, Plate CLXI).

The idea that this large group of vessels probably represented a temporary storage situation for vessels which would be used for storage is supported by Pepper's observation that a cylinder jar found in Room 32 contained 9 flat circular turquoise beads and 2 shell beads. Were these jars, thus manufactured for the storage of luxury items? Detailed examination of the cylinder jars recovered by Pepper, now housed at the American Museum of Natural History, has yielded previously unreported features of these vessels which offer additional clues on their origin and use.

There is some uncertainty concerning the number of cylinder jars that were actually recovered from Bonito (see footnote 49, p. 210, Judd 1954). Judd claimed to have found 17, but 16 jars were listed as found in Rooms 320, 326, 329 and 330 where 68 bodies were buried and two other jars were recovered from Rooms 251 and 309. The subsequent disturbance of the bodies in the four burial rooms has made it difficult to determine the exact association of the jars with the bodies.

Pepper found the greatest number of cylinder jars, most of which were found stacked in Room 28. Pepper claims to have recovered 114; but only 111 are listed in Hyde's Table 2 (Pepper 1920:359-362). In addition, 8 were found in Room 28B; 19 in Room 39B; 1 in Room 53; 2 in Room 33 and 4 in Room 32. Fragments of an unknown number of jars were found in Room 52, the second story room above Room 32. If the larger vessel count is used, 148 whole jars were found. Adding the 18 Judd recovered, a total of 166 cylinder jars have been found at Pueblo Bonito, 70% of which were stacked in Room 28.

In December, 1976 I was able to examine Pepper's collections at the American Museum of Natural History, but could only locate 109 of the 148 cylinder jars he recovered. Table 1 lists the proveniences and numbers of jars Pepper found and those I located at the museum. Nevertheless, I was able to analyze 74% of all jars that Pepper recovered from the 5 rooms (28, 32, 33 39B and 53); 75% of all jars that Pepper recovered from Room 28, and of these, 74% of the decorated jars.

Pepper also recorded the various kinds of handles on the jars. Table 2 lists those he found and those I was able to locate and study. I located all four of the vessels with unusual handle arrangements: the polished red vase with no handles; one with a strap handle, and two with perforations for hanging. Of the other 110 vessels, 80 have 4 handles and I was able to study 92% (74) of these jars.

The first remarkable aspect of these cylinder jars is their uniformity in size and shape. The 109 vessels examined have a mean neck diameter of 10.4 cm; mean base diameter of 10.4 cm; and mean height of 23.7 cm. A scattergram of the relative jar sizes by height and neck diameter shows the decorated jars to be more tightly grouped around the mean height of 23.7 cm than the plain jars (Figs. 1a, 1b). It is also clear that the variation that exists in jar size is in the range in neck diameter, not in height. There is no discernable difference in size among vessels with 3 or 4 handles or those with handles oriented vertically or horizonally. Neither are there size differences in the jars from Room 28 compared to those from the other rooms.

It is clear, however that twice as many undecorated jars had four handles oriented vertically, but that about five times as many decorated jars had four handles oriented horizontally (Table 3). A functional reason for the difference is unclear since either vertical or horizontal loop handles would allow the vessel to be hung in similar fashions. It may be that, although there was no great size difference between decorated and undecorated jars, the difference in orientation of the handles is indicative of a stylistic difference between the work of two potters. It is also clear (Fig 2) that the potter who designed the vessels with four handles oriented vertically allowed half as much variation in neck diameter as did the potter who designed the jars with four horizontal handles.

Evidence that these Room 28 cylinder jars were the work of one or, at the most, of a very few

TABLE 1 Cylinder Jars from Pueblo Bonito

Room	Number of Vessels Analyzed		
	Pepper's sample	Washburn's sample	
		Decorated	Undecorated
28	114	49	38
28B	8		
39B	19	10	6
32	4	3	1
33	2	1	1
53	1		
	148	63	46

TABLE 2 Distribution of Handle Types from Pueblo Bonito

Handle Type	Number of Handles Analyzed	
	Pepper's sample	Washburn's sample
none	1	1 (polished red)
perforated	2	2 (undecorated)
strap	1	1 (decorated)
2	1	
3	23	18
4	80	74
unknown	6	13
	114	109

TABLE 3 Distribution of Handle Types on Decorated and Undecorated Jars, Pueblo Bonito

	3 Handles Vertical	3 Handles Horizontal	4 Handles Vertical	4 Handles Horizontal
Decorated Jars	4	1	8	39
Undecorated Jars	8	5	16	8

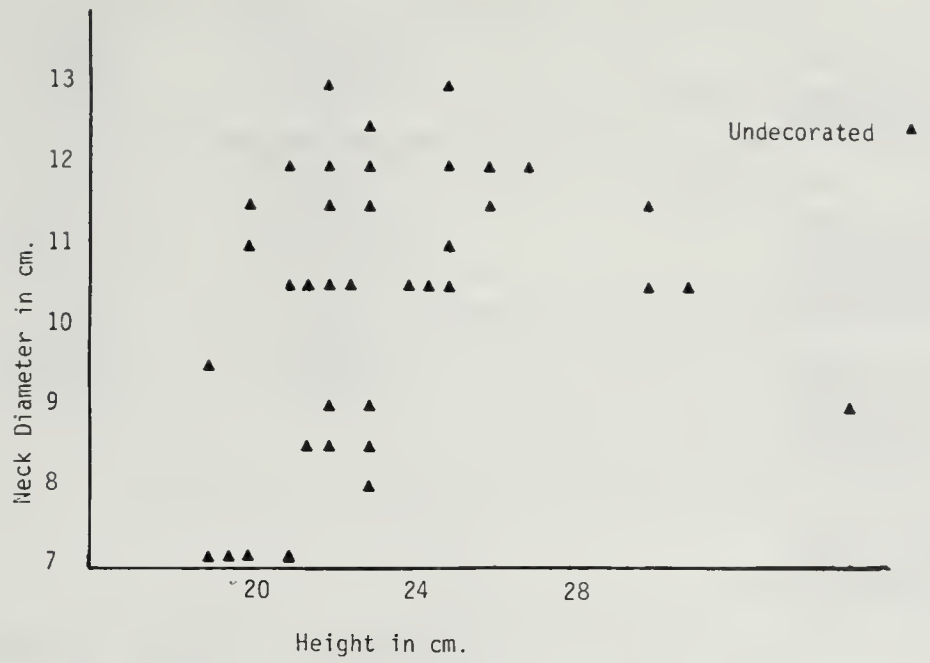


Fig. 1a

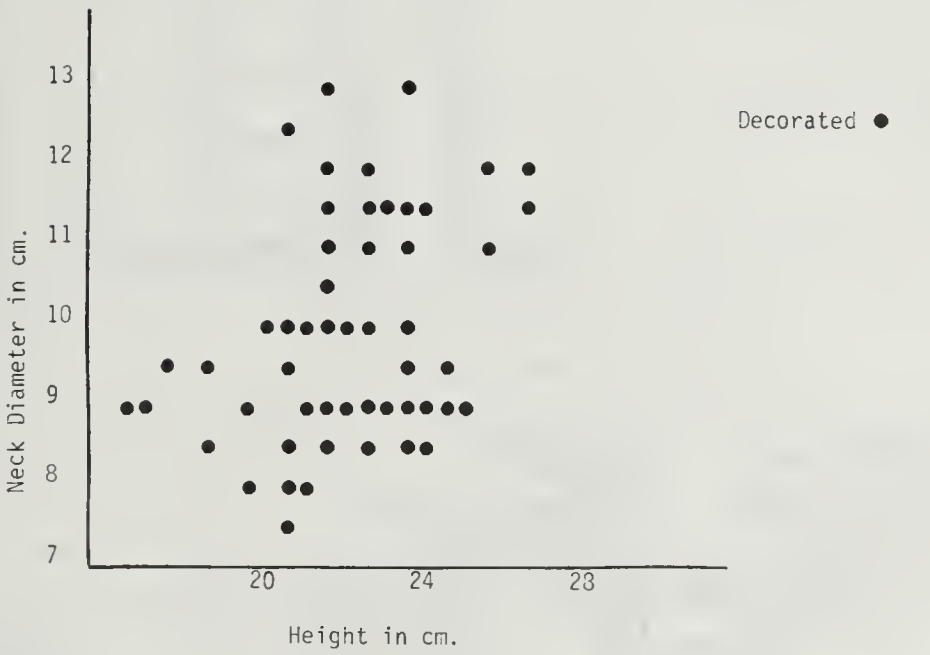


Fig. 1b

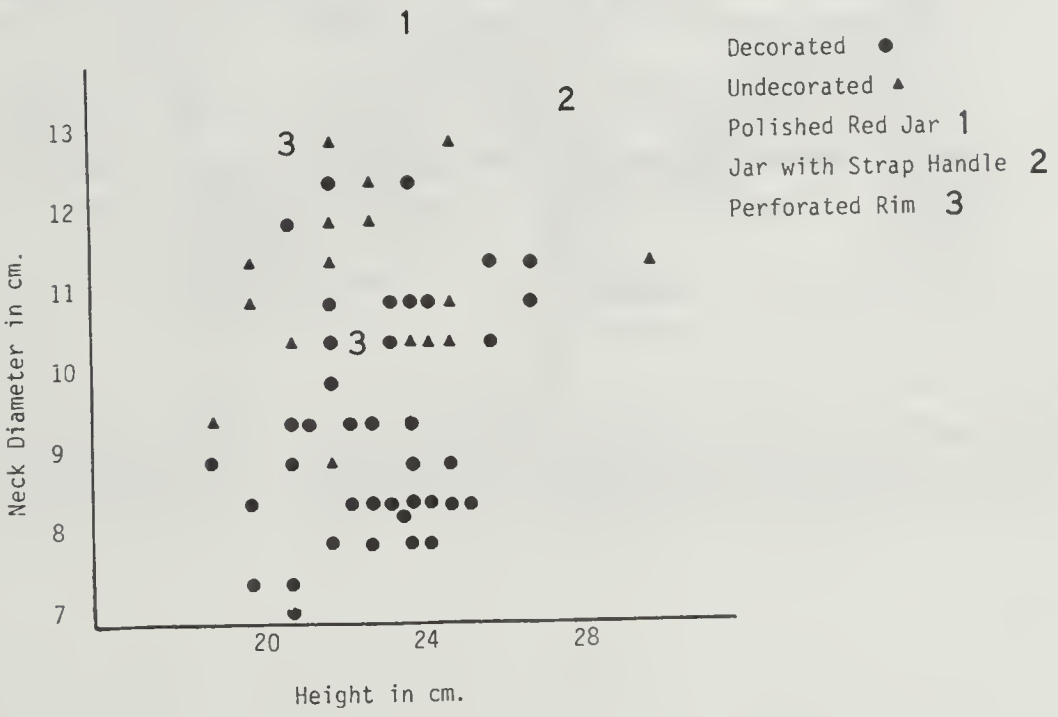
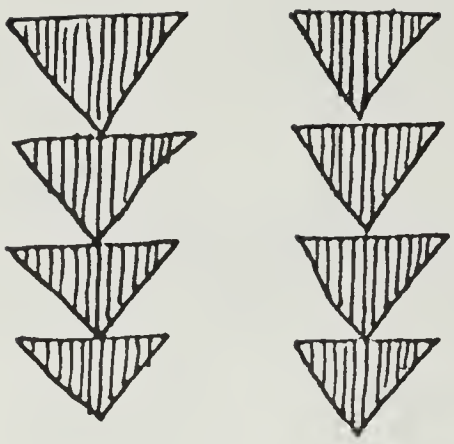


Fig. 2

A



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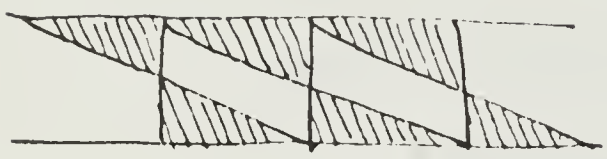

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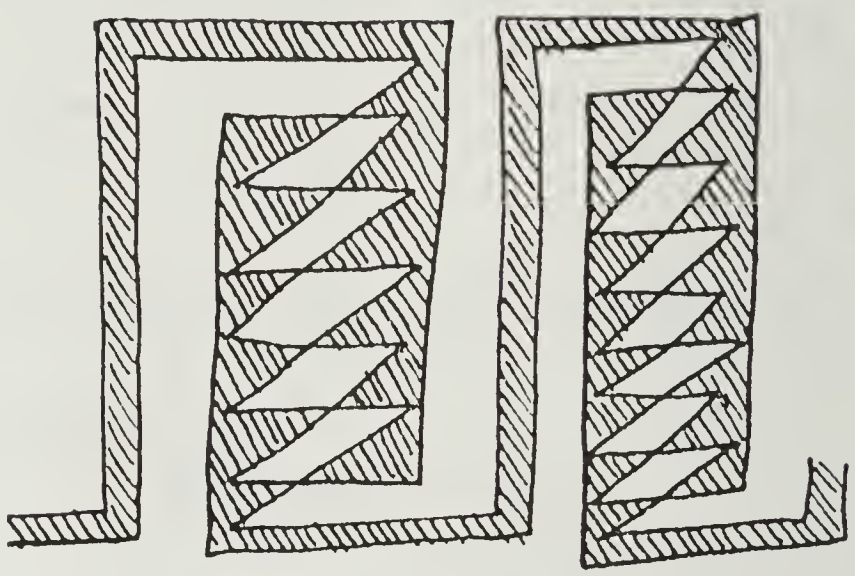
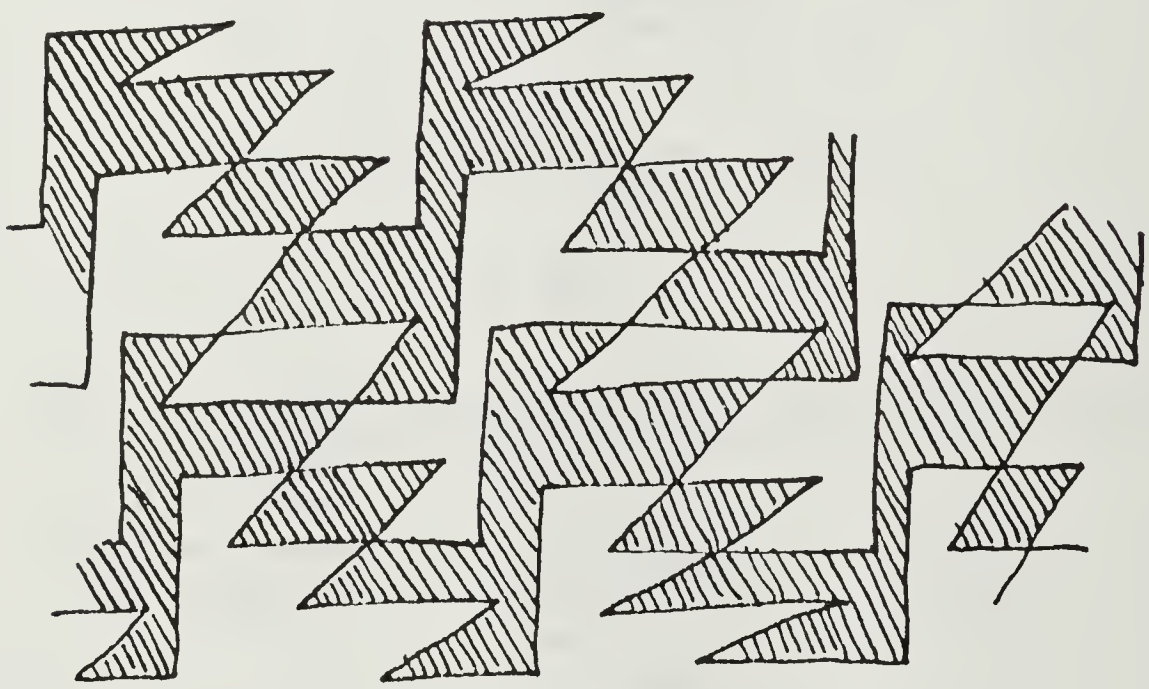


D



E

Figure 3 Repeated Designs found at Pueblo Bonito
A) 6 repeats B) 8 repeats C) 5 repeats D) 9 repeats E) 10 repeats

potters, comes from close examination of the construction techniques and workmanship and the manner of design execution. All are fairly well smoothed; some have a thin slip which does not always cover the gray clay base. The black hatched designs have frequent overlaps where the hatching lines which fill the pattern go beyond the edges of the pattern outline. The sureness of the line application and general demeanor of the design on the 66 decorated vessels all bespeak of the work of one or, at the most, several potters.

It is notable that only 66 vessels are decorated; 42 are simply finished with a plain white slip. Were these vessels to be decorated at some later time? If so, why were they stacked with vessels apparently completely decorated? It may be that these 48 vessels were never intended to be decorated and that the reason which caused 114 cylindrical vessels to be produced was so urgent that there was time to decorate only slightly more than half of them. It should be noted that the cylindrical vessels in burial contexts in Monte Alban tombs are not decorated, but merely have a smooth gray surface; some are lightly polished.

Other evidence which suggests the ''mass-produced'' workship nature of these cylindrical forms is the identical nature of the designs. Repetitive use of a pattern is almost non-existent on Anasazi wares where the same design elements are repeated but there is endless variation in the specific ways they are combined. On the 52 decorated cylindrical vessels analyzed several patterns were repeatedly painted on a number of vessels and they appear to have been executed by the same hand.

In particular, five patterns were used more than twice on vessels that Pepper recovered from Bonito and three of these patterns also appeared on jars that Judd found in rooms in another part of Bonito (Fig 3). There are four other designs which appear once on jars from Pepper's rooms and once on jars from Judd's rooms. This use of identical patterns on jars from two areas of the pueblo suggests that all the jars were made in the same workshop and/or by the same potter(s) and were found in different rooms by virtue of their special use in a funerary context. A further interesting aspect of these repeated designs is that they are all, with one exception, found on cylinder jars with four horizontal handles. This lends ever more support to the idea that one person executed jars with vertical handles while another did those with horizontal handles.

All but one vessel from the pile in Room 28 were decorated with black-on-white designs. The exception, H-3378, is a plain, polished red vessel with sloping rather than vertical sides and no loop handles or hanging holes (16 cm diameter; 24.2 cm height). Pepper suggests the ''. . . possibility of this piece having come from some other part of the country to serve as a model for the potters in making their white ware.'' (Pepper 1920:120). Plain red polished jars of cylindrical form are known as early as the Pueblo I period with the Abajo wares and later with the Pueblo Black-on-red and Wingate Black-on-red types.

The three Pueblo Del Arroyo polished red jars from Room 15 (Plate 55 a,b,c) have a mean base diameter of 8.2 cm, a mean neck diameter of 15.0 cm and a mean height of 25.1 cm. These figures are closer to the size of the polished red jar from Room 28 of Bonito (whose base diameter is 8.5 cm; neck diameter is 15.0 cm; and height is 24.6 cm) than they are to the smaller size of the other black-on-white or plain slipped white vessels with a mean base diameter of 10.4 cm; neck diameter of 10.4 cm and height of 23.7 cm. The high degree of similarity in size and surface treatment between the red Bonito cylinder jar from Room 28 and the three jars from Room 15 of Pueblo Del Arroyo seems to suggest that they are all imports, or if they were made locally, they may have been made by the same person/workshop.

One very important difference relevant to the problem of which jars were locally made and which were imported, possibly as models, can be noted in Figure 2 where the dimensions of the polished red vessels (#3378) and the decorated jar with the strap handle (#3381) were plotted and compared to the decorated and undecorated jars with four loop handles. It is immediately clear that both the polished red and strap-handled jars are well outside the size range of the major group of cylinder jars found at Bonito. If these two outsized jars fell within the mean size of the other

Bonito jars (as do the two examples with hanging holes), the difference in color or handle type themselves would offer less evidence of their Mesoamerican origin. However, the difference in size in conjunction with the color and handle differences strengthens the possibility that these two vessels were not made by either of the potters who produced the other docorated or undecorated jars, and thus, that these jars may be imports.

Given all these observations, it is now possible to suggests that this pile represents the work of artisans specifically directed to ''mass-produce'' a quantity of pottery of a specific form probably for a specific function. This high degree of identity in design and form is atypical for the Anasazi and suggests that their source of inspiration lies outside the American Southwest.

Although earlier Teoihuacan potters produced cylindrical vessels, these were much shorter, stood on tripod legs, and had fesco and/or incised designs. Another potential source of influence are Late Classic Mayan vases which, although shorter and typically slipped orange and painted with detailed activity scenes and glyphs, do exhibit the same cylindrical, flat-based plain rim form (Rands and Smith, Fig 16, 1965). By early post Classic times many of the Mayan jars carried incised rather than painted scenes (Smith and Gifford, Fig. 10, 1965; Shook, 1965) which were placed in bands around the vessel or in patterns which covered the greater portion of the jar. The red background color and the period of manufacture suggest that they could possibly be prototypes and thus that the one cylinder jar from Room 28 those from Del Arroyo may well be imports.

Finally, mention should be made of plain black cylindrical forms in Late Classic San Juan Plumbate (Shepard, 1948, Fig 7). This is a ware type which may have largely been made in Guatemala and traded widely throughout Mesoamerica. Pepper cites vessels recovered from Finca Pompeya in Guatemala as being similar to the Chaco cylinder jars (1920:121-122).

> They range from 5 to 11 inches in height and from 3 to 5 inches in diameter. One is of a light buff color and would readily pass as a specimen from Bonito, so nearly does it approach some of the specimens from Room 28. the ornamentation of this piece is confined to a band of decorative lines near the rim; in fact, almost all of the decorations are confined to this part, some have painted bands of solid color, some incised lines and figures, some raised lines. Most of the pieces are dark, either a dark red or a dull black, no handles are in evidence. . . .''

These are apparently Plumbate forms (cf. Seler 1904b, Fig 15, p. 86; Seler 1961, Fig 242; and Seler-Sachs, 1925:219).

In short, cylindrical vessels appear to be an endemic form in Mesoamerica throughout the pre to post Classic periods.

However, the closest analogs to the Chaco cylinder jars are those from Monte Alban. It has usually been assumed that the complex cultures in the Valley of Oaxaca were too far away to have affected developments in the American Southwest; at least no mention has been made in the literature of the extremely close similarities between the cylinder jars and duck pots from Monte Alban and Anasazi forms. I suggests that distance may not be a mitigating factor.

According to Caso, Bernal and Acostas' monumental compendium of the ceramics from Monte Albán (1967) the cylindrical vessel form was made and used throughout the occupancy of the site, often found in quantity as grave furniture. Fragments of large gray jars narrower at the neck than at the body center with four holes perforated near the rim were recovered from Period I (400-100 BC) burial V-19A (Caso et al., 1967, Figs. 161, 173). Caso, Bernal and Acosta suggest that these vessels may have been suspended with a cover to protect the honey contents from insects and animals. (Caso, Bernal and Acosta, 1967:203). Two other Monte Albán I examples are jars with flat bases ranging in diameter from 5.5 to 6.5 cm in diameter and 12 cm high without suspension holes that are of cream clay (Fig. 77) and gray clay (Fig. 82a). The former contained an obsidian knife. These were not found in a burial context but in Mounds Y and YW respectively and may suggest their use as containers for luxury goods.

Period II (100 BC-AD 200) cylindrical jars are more numerous; 118 examples were recovered

(Caso et al., 1967, Figs. 215, 217, 238-240). Generally the height of these jars is twice the diameter; the bases are flat and they have a plain or slightly polished surface of a cream to brown or gray clay. Some have smaller mouth diameters than bases; others have smaller bases than mouth diameters. Another common form during this period are jars with rims indented to receive a flat lid.

During the Transition from Monte Albán II-IIIA several types of jars were made. Jars with flat bottoms and plain rims are now larger (15 cm high and 9 cm in diameter). These were recovered in tomb contexts as were a new variant measuring 16 cm high and 7 cm in base diameter which had two vertical loop handles (Caso et al., 1967, Fig. 260). Apparently, the plain-rimmed jars were not produced in quantity, or at least were not recovered, for their numbers decreased by Monte Albán IIIA (AD 200-550). However, Monte Albán IIIB (AD 650-900) the plain forms again predominate. These generally have a greater diameter (10 cm) while maintaining a height somewhat less than twice the diameter. Even during the demise of Monte Albán as a ceremonial center during Period IV (AD 900-1350), the vases continued to be produced, although in smaller frequencies. Later varieties have slightly outcurved rims; some have vertical loop handles evenly spaced around the jar below the rim. These later forms in particular recall Bonito jars.

It is puzzling that so little was found in the many jars recovered at Monte Albán. Perhaps they were no different from the other funerary furniture, hastily made in quantity to be piled beside the deceased. Linne observed one instance among the grave furniture at Xolalpan, Teotihuacan where a candelero had been placed inside a tripod vessel and''. . . on top of the latter was set an undecorated and footless cylindrical vessel, also mouth upwards.'' (Linne 1934:59). This stacked placement suggests that the vessels were never intended to contain anything, but to serve as token offerings for the deceased.

Since the cylindrical vessels which most resemble those from Bonito were made at Monte Albán in period III, especially IIIB, this would enable them to slightly predate the building activity of the early 11th century in Chaco Canyon, the period in which presumably these black-on-white hatched cylindrical vessels from Room 28 were made. The connection between the two areas is of course open to debate since although there is a fair degree of similarity in vessel form between the two areas, the Monte Albán jars are plain gray, while the Chaco jars are slipped white and decorated with black hatched designs. Wholesale identical borrowing of a trait is an infrequent cultural response; more frequently cultures absorb and revise a trait to fit their own system. In this instance, for some reason, perhaps functional, the formal properties were slavishly copied, but they were decorated within the local black-on-white tradition.

To strengthen the case that these jars are indeed related to those from the southern highlands, despite the different decoration, I describe one aspect of formal identity which would only have occurred by slavish copying. Recalling that some Monte Albán I II cylinder jars had small vertical loop handles near the rim, it is notable that the same handle type occurs on vessels from Bonito, although here in both vertical and horizontal positions and in series 3 or 4 loops around the jar rim area (Fig. 4). Of the 109 jars examined, 63 had horizontal loop handles, 38 had vertical loop handles, and 8 either had no handles or the rim area was missing and thus could not be observed. Of the 109 jars, 19 had 3 handles, 73 had 4 handles, and 17 had no handles or it was impossible to determine how many handles there may have been.

Close examination of the handles on the Bonito jars revealed that they had never been used for hanging, as was suggested by Caso et al. (1967). The thin loops of clay had been pressed on after the main vessel body was formed. Although the jar body surface was smoothed, the area on the inside of the loop between the vessel wall and the lop was not smoothed since it is not readily accessible or visible. It is this area which gives the critical clue of slavish copying, for here are found small pieces of clay still sticking out from the unsmoothed loop. If the vessel had been hung, these small pieces would have been worn off. However, they still remain, clues that these handles were slavishly copied from some jars where handles were functional requirements. Alternatively, the Chaco jars may have been just manufactured and piled in Room 28 awaiting use. If this is the case,

Fig. 4

Fig. 5

Fig. 6

then the claim that the handles are vestigial copies cannot be supported. However, there are two other aspects of these handles which eliminates this latter possiblity.

On several Bonito jars, the handles appeantly fell off after they were applied. Perhaps this was due to hasty or faulty application procedures, or perhaps it was due to the potters' inexperience with the local clays. In any case, the handles were not reapplied, but rather the join area was smoothed over and the vessel was slipped and decorated in the usual manner (see Fig. 5). Since the handles were evenly spaced around the neck area, loss of any one would cause the jar to hang at an angle. If, however, these jars were intended to be hung, the potters would presumably have taken care to insure that the full complement of handles was on every jar. The fact that some are missing, but that the jars were finished anyway (i.e., painted) strongly suggests that they were never intended to be hung.

The second aspect which suggests that the handles on the Bonito jars were vestigial and that at least some of the jars were actually used is a series of use marks observed on the inside of several jars (Fig. 6). They are clearly not finishing marks, but are grooves made after the clay was hardened and fired. Some of the scratches occur near the base, others near the rim, and others near the center. They appear to suggest marks caused by inserting and removing an item too big for the jar. The item would have had to have sharp edges to have caused such scratches. The hardness of the vessel wall indicates that an object of at least equal hardness rather than food or liquids would have causes such scratches. Since obsidian and shell were found in Monte Albán cylinder jars, I suggest that these vessels may have been used to store the raw matrix of shell or turquoise, and it was the edges of matrix which may have scratched the vessel walls as it was being placed in and out of the jar.

In sum, from the above evidence, the loci of Mesoamerican influence—at least for cylinder jars—appears to be in the Valley of Oaxaca, although the red slipped jars from Bonito and Del Arroyo argue for a Mayan source. What is clear, however, is that the cylinder jars from Bonito, both in their unusual contexts and in their formal characteristics, are not typical Anasazi containers. In fact, the vestigial nature and lack of use of the loop handles, the unusual interior wear scratches, and the uniformity in vessel size and design would suggest that these jars were manufactured, perhaps after a model brought from Mesoamerica, by several potters for some special function, probably related to the activities of the few pochteca who may have lived at Bonito.

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TABEL 1 Cylinder Jars from Pueblo Bonito

Number of Vessels Analyzed

Room	Pepper's sample	Washburn's sample	Undecorated
28	114	49	38
28B	8		
39B	11	10	6
32	4	3	1
33	2	1	1
53	1		
	148	63	46

TABLE 2 Distribution of Handle Types from Pueblo Bonito

Number of Handles Analyzed

Handle Type	Pepper's Sample	Washburn's sample
none	1	1 (polished red)
perforated	2	2 (undecorated)
strap	1	1 (decorated)
2	1	
3	23	18
4	80	84
unknown	6	13
	114	109

TABLE 3 Distribution of Handle Types on Decorated and Undecorated Jars, Pueblo Bonito

	3 Handles Vertical	3 Handles Horizontal	4 Handles Vertical	4 Handels Horizontal
Decorated Jars	4	1	8	39
Undecorated Jars	8	5	16	8

AN OVERVIEW OF THE GALISTEO ARCHAEOLOGY

Bertha P. Dutton

ABSTRACT

At the 50th anniversary of the Pecos Conference, at Pecos Pueblo ruin, a session was devoted to "The Rio Grande Perspectives from its Periphery." Afterward, one who had attended the original conference remarked: "I thought the Rio Grande was a 'squeezed lemon.' That session told me it wasn't so!" One small area, the Galisteo Basin south of Santa Fe, has come to be viewed as an exponent of Rio Grande Anasazi culture. Although perhaps true in part, other important factors must be considered. This paper sets forth evidence of non-Anasazi features of the Galisteo culture area, with a view to better establishing its place in archaeological history.

As an anthropology student and then as an employee of the University of New Mexico, my archaeological investigations were initiated in districts east and northeast of Albuquerque. Ruins in Tijeras Canyon and its tributaries became known, as did those of the valley and flatland stretches which arc about the northeastern extrimity of Sandia Mountain, and others strung along the borders of the Galisteo Basin—an eroded treeless depression lying some 40 to 65 km. northeast of that mountain, and within 30 to 50 km. south of Santa Fe.

According to historical documents and early maps this area embraced the old Tanoan Province—homeland of the Tanoan-speaking Indians, wherein dialects known as Tano, Tiwa, and Tewa had been spoken. Slightly peripheral thereto were significant ruins in the Pecos country northeast of the Galisteo Basin, and in the Jemez mountains to the northwest. In each of those districts Tanoan tongues were spoken. Jemez people, whose desendants now reside in a single pueblo known as Jemez, speak the Towa dialect. When the pueblo of Pecos was abandoned in 1838, its seventeen remaining inhabitants sought and received permission to join their close kinsmen at Jemez. They moved across the mountains, intermarried with the Jemez Indians, and have continued their blood lines speaking Towa.

Shortly after I joined the School of American Research-Museum of New Mexico entity in Santa Fe (henceforth mentioned as "the Museum"), I was invited to prepare a paper for the approaching commemorative centennial of the birth of Adolph F. Bandelier on 4 August 1940. As a result, the publications treating of Bandelier's investigations in the Southwest were studied carefully.

Weekends and holidays were frequently spent with Bandelier's "Final Report of . . . Indians of the Southwestern United States" (1890-92) at my side while I piloted my Modal A Ford to locations which he described. His works and N.C. Nelson's small book of 1914 on ruins of the Galisteo Basin provided information which led to sites identified as Tano and others as Tiwa. I was acquainted already with San Pedro Viejo Laboratory of Anthropology (henceforth cited as LA), Museum of New Mexico, Archaeological Survey number 162 or Paako as called by the Tewa-speaking Indians. Nelson noted nine or ten principal ruins of the Tano group. Of those I came to know, one is El Tunque (LA 240), or "Village of the Basket" in the Tewa tongue. Nelson excavated 218 rooms there. During the 1960s, Franklin Barnett and associates of the Albuquerque Archaeological Society conducted partial excavations at that site. Barnett (1969) report no fewer than 42 pueblos in the Tano district at the time of the arrival of the Spaniards.

From El Tunque, the Rio Galisteo and mountain trails gave easy access to the Galisteo Basin and sites that Bandelier and Nelson had identified. The fact that the two early investigators differ on certain locations is not of concern to this paper. My major attention became centered in the Galisteo ruins.

I had observed that adobe was the conspicuous building material in Tano sites, where the adobe or clay and boulders were intermixed, the latter being used especially for wall footings and fill-ins.

The chief pueblo in the Galisteo Basin was called Los Tanos (LA 26), or old Pueblo Galisteo. Bandelier recorded its name T'a-ge Uing-ge, and Harrington as Tánuge'ongwing (1916:481). The long abandoned settlement appears now as an extensive array of low adobe mounds, open areas, and scattered boulders among which potsherds and other visible cultural items do not appear in abundance (see Nelson 1914:103-109).

Elsewhere, major ruins built of sandstone were in evidence, roughly eight to twelve kilometers from each other. I came to know them well. Surface sherds and a few artifacts were collected. Less obvious masonry ruins occur in greater number. I was surprised to find that archaeologists had given the Galisteo region little or no attention since the days of Bandelier and Nelson. If found that Nelson's seven months of test excavations made in 1912 were practically as he had left them. Partial chambers which he had feared would soon slump into the arroyos or rivulets, were still very similar in appearance to photographs of the features taken in 1912. Why didn't we know more about this near-at-hand and culturally important area?

Through the years, and particularly after the first Pecos Conference of fifty years ago, a general assumption had developed—based primarily on similar appearances of pottery sherds—that when the Mesa Verde Province was depopulated, people therefrom had migrated to the Galisteo Basin. Dendrochronology dates (''dendrodates'') indicated that some Galisteo pueblos were founded during, or shortly after, the Mesa Verde abandonment. The coincidence was intriguing but, I believe, misguiding. If such a migration had occurred, it seemed reasonable that more than ceramic similarities should be found in the Galisteo region. Firm evidence needed to be established. I devised a project along the lines of Emil Haury's concept of conditions necessary to the proving of actual movements of people from one place to the other (Haury 1958:1-6). I then turned to the Galisteo, surveying for likely sites to prove or disprove the theory.

Finally, in 1951, with permission and full cooperation of the Sawyer Cattle Company of San Angelo, Texas—then owner of a huge ranch on which five major ruins and many other sites are situated—excavations and laboratory work were begun at the easternmost and smallest of the large Galisteo ruins, Pueblo Largo (LA 183).

Pueblo Largo is situated on a red sandstone promontory, roughly 30-35 meters above the Arroyo Estacado, the valley of which afforded rich farming plots. Bounding the flat lands is a semi-forested plain with interspersed open, short-grass stretches. A spring was at hand, as were several water holes. Nelson estimated 480 ground floor rooms, and a second story half as large. He excavated ten well dispersed rooms. We worked there for six short seasons, in a number of diverse buildings. We fully cleared dwelling and storage rooms, kivas, and a circular tower, and ran several stratigraphy tests. Plaza 5, on the northernmost limit, by reason of its black-on-white pottery, appeared to be earlier than other sections of the ruin. We concentrated efforts there in room clusters and the tower (Dutton 1951:365-366; 1953:341-351; field notes 1948-1953).

In the belief that readers are acquainted with the details and characteristics of features and facts to which reference is given here, my remarks will be direct. First, a few words in brief review of the black-on-white pottery situation: Suddenly, in the Santa Fe region, about A.D. 1225 (Stubbs 1953:48-91) a *new type* appeared. Its carbon paint decoration was compatible with the idea of Mesa Verde derivation. This was named *Santa Fe Black-on-White.* Later, another new type was identified. Its thick-slipped surfaces decorated with carbon paint were commonly crackled, causing it to be called ''Crackle Black on white'' by the Pecos archaeologists. Later on, H.P. Mera (1935:20) named it *Galisteo Black-on-white,* and designated Forked Lightning ruin (across the valley from the main ruin at Pecos) in its late period, as the type site, which he considered to be ''a Mesa Verde type in the Galisteo region.'' (I may note that only most generally is Pecos ''in the Galisteo region.'') However, the crackle ware and other black-on-white and black-on-grey specimens, e.g., *Wiyo Black-on-grey* and the ''Biscuitwares'' (Biscuit A, later named *Abiquiu Black-on-grey* and Biscuit B, named *Bandelier Black-on-grey)*—all members of the carbon paint tradition—were associated with early glaze-decorated designs on red background: Glaze I Red and other Glaze I (or Glaze A)

variants. The glaze-decorated types appeared to be dominant from ca. A.D. 1300. The black-on-white types, which may date some years earlier in the Galisteo than near Santa Fe or at Pecos, dwindled. They, in turn, were replaced by glazes, recognized as having originated in the West—in the Little Colorado locations to a large extent. These glaze-decorated wares developed in sequence. They lasted through the life of certain pueblos, and into Spanish or post-Spanish times at others.

Glaze I Red is earlier in the Galisteo than at Pecos, where it was said to have been made "near the end of the period for the site" (Shepard 1942:199). In the Galisteo Basin, Glaze I Red (presently called Aqua Fria Glaze-on-Red) consists of a mixture of intrusive pottery from several districts; and some was locally made. Glaze I Yellow (now called Cieneguilla Glaze-on-Yellow) is said to have originated in the Galisteo region, where it developed—as modern dating techniques indicate—during the span of time various pueblos were occupied. These were all pottery types observed, or expected as being present at Pueblo Largo.

Our work resulted in good cultural evidence, and yielded dendrodates from Plaza 5 and from four other sections of the ruin. Indications are that Pueblo Largo was founded in the mid-1200s and that it was inhabited into the middle and probably late 1400s (Robinson, Harrill and Warren 1973:35-38), when glazed-decorated types predominated. The so-called Galisteo Black-on-white sherds and Chupadero Black-on-white of Mimbres branch Mogollon derivation were associated *under* wood specimens dated at the end of the 13th century (A.D. 1275+, 1295, and 1299). The tower structure there yielded ten indefinite dates which suggest use near A.D. 1300. In the fill of Corner Kiva XX, black-on-white sherds predominated; these date from the early 1200s through the mid-1300s.

This kiva was built with a curving wall abutting on two straight ones, the juncture of which formed a right angle. There, a floor-to-ceiling flue was built of rock, with a small, rectangular opening at the base which permitted an inflow of air to rise to the top of the wall (cf. varying vent features, Holden 1955:105-107; Kidder 1958:35-42; Dutton 1963: 198 note 597). A Wiyo Black-on-grey bowl rested atop the air duct—which, presumably, was open through the roof.

A circular underground kiva located to the west of Nelson's Refuse Mound B (Nelson 1914, map following p. 68) was excavated to a depth of about one meter. Termination of our work at Pueblo Largo precluded determining its special features. What we had unearthed and placed in repository at the Museum gave no evidence that Mesa Verdeans had occupied this pueblo. Architectural expressions were of Rio Grande type, as those are currently understood, and ceramics were not like those of Mesa Verde. The latter merely had certain design likenesses, and decoration on some black-on-white specimens was with carbon paint.

From the artifacts recovered, and from research, a chapter of Galisteo Basin prehistory can be written for Pueblo Largo. Much of the material has been analyzed by specialists, an extensive list of dates correlated with certain features, and texts prepared. Unfortunately, the ranch changed hands, resulting in an end to cooperation with scientists, or anyone else. Much now appears to be out of bounds including lesser ruins, circular structures, water use patterns, extensive pit house sites, and much other important cultural evidence. The property is owned by a land development concern in the East.

Already, I had located a promising site for pursuing the migration theory. Following my objectives it was necessary that attention be given to site location, settlement pattern, architectural details and orientation, characteristics of all artifactual items, economic conditions, and a gamut of things that might suggest the origin of some or all the inhabitants of the Galisteo region.

Up the highway a few kilometers toward Santa Fe, Site LA 309 had been visited by Stallings and Stubbs (Stallings 1937), who had tested six rooms and obtained dendrodates. A medium-sized masonry pueblo was there on a yellow sandstone eminence. Its building blocks are similar in color and durability to those of Mesa Verde; some show dimpling. Black-on-white sherds predominated but Glaze I Red and Glaze I Yellow types were identified, all of these being considered as indigenous. Trade wares were listed as Chupadero Black-on-white, Wingate Black-on-red and Spr-

ingerville Polychrome, and "Mesa Verde Black-on-white" (Smiley 1951:31). Because I can remember names better than numbers, I called the site Colina Verde.

Dendrodates place occupation of the pueblo as ranging from the 1260s to the mid - 1300s. "The numerous clusters of cutting dates in most of the proveniences suggest considerable prehistoric mixing of material either through use as refuse area or from collapse of upper stories. They do not necessarily indicate successive reconstructions or modifications" (Robinson, Harrill and Warren 1973:18). Someone had cleared a subterranean circular kiva, which is not mentioned as such in reports published by the Laboratory of Tree-ring Research, University of Arizona (Ibid. and Smiley, Stubbs and Bannister 1953). Here, too, is a Galisteo chapter to be written.

As an employee of the Museum, I had applied for a National Science Foundation grant to excavate there. The grant (No. G24141) was received but by then I had no place to use it! Denial of access to the ranch forced me to survey outside of its some 83,000 acre boundaries. By walking and driving where possible, and by flying over all abutting properties, I concluded that the next best site on which to utilize my grant was a small pueblo (LA 25) atop a yellow sandstone promentory of the Galisteo Formation, a short distance up the Rio Galisteo from the village of the same name. There, black-on-white sherds predominated on the surface, with Glaze I Red also occurring. This was a drawback.

Fred Wendorf had advised me to locate a "pure Galisteo Black on White site." One day I stopped off U.S. Highway 285 to take a telephoto picture of Pueblo Largo, about one kilometer distant, and found myself standing amidst a thick scattering of black-on-white sherds. A road grader had just cleared weeds from the pavement edges and exposed ash layers and ruin features. Here was an old site within the forbidden ranch holdings, but located on the highway right-of-way, and thus possible of excavation. The Museum recorded it as LA 3333 and arranged for its excavation—in which I participated to some degree. Masonry structures, undercut pit houses, and two circular kivas of Rio Grande type were found within our permitted limits. Beyond, cultural remains extended on both sides of the roadway. The pottery was all black-on-white, with Heshotauthla Polychrome derivatives, St. Johns types, and other trade varieties in small amounts. Dendrodates have indicated that one of the kivas may have been constructed near the beginning of the thirteenth century (Robinson, Harrill and Warren 1973:56).

By then I was getting very suspicious about the so-called "Mesa Verde Black on White," which continually appeared in association with ceramic types that emanated from other than the Mesa Verde Province. Why shouldn't at least some of the black-on-white specimens found in the Galisteo Basin have originated in the West, as did the black-on-red wares, early glazes, and plychromes of the Little Colorado drainage? Could some even have been locally made? All the necessary raw materials are present locally. At one site (LA 6869) near the Waldo Dam, which has been built on the Rio Galisteo, we have an all Glaze I Red pueblo (Alexander and Warren 1971).

At Central Arizona sites were many ruins where pottery showed crackled slip, and carbon paint was used to decorate such types as Tusayan, Kayenta, Walnut, and other black-on-white pottery—all contemporary with Galisteo materials. Did these carbon decorated types in the Galisteo bespeak an influx of western traits arriving in the East, or possibly a migration of small groups of Indians who scattered into various available locations? The great drought period at Mesa Verde in the late 1200s also affected the Little Colorado peoples at the same time. In the Rio Grande, a drought had come and gone; conditions were then favorable in the Galisteo and Tanoland.

After considerable delay I was permitted on the Frank Ortiz y Davis ranch to excavate at LA 25, across the Rio Galisteo from the extensive adobe ruins of Pueblo Galisteo (Los Tanos)—which existed into historic times. Nelson had considered LA 25 to be outlying part of Pueblo Galisteo, and had excavated one room in that masonry ruin. Nothing had been molested since 1912, when Nelson did his testing.

Structures, shown by outlines of stones and by standing walls of ashlar type, gave evidence that originally practically all of the space available had been occupied by the pueblo. The architec-

tural plan revealed a north-south axial wall extending through two or three room clusters as the "backbone" of the settlement (cf. Schwartz and Lang 1973:18, 43). It still is prominently observable 700 years after its erection. From it certain walls were built across the breadth of the central room cluster which extends to six or seven rooms in width. Otherwise the walls were independently laid up, with conspicuous jogs and offsets. All rooms are four-sided, but they show variations, particularly in wall lengths. (Grounds plans resemble those of Showlow and Ridge Ruin, e.g. Haury and Hargrave 1931 and McGregor 1941).

No floor features were built in any of the dwelling rooms. Fires had been laid directly on the floor, in or near one or more of the corners. The lack of inside fireplaces may indicate the use of outside earth-oven cooking—which was an old Mogollon trait (Haury 1942:20). No wall niches were found. In one instance only (Room 22) evidence of a doorway was noted. It had been rocked-in and plastered over continuously with the wall plaster. Not until after a period of erosion did it become discernable. At one time it may have led to the exterior.

The pueblo achieved a terraced appearance because of its placement on the bedrock, which tilts from east to west. It was a one-storey structure. No attempt was made by the inhabitants to work the bedrock to an even plane, as was the pattern in the Mesa Verde Province. Instead, small rocks were distributed over the low places and adobe packed between and over them to achieve relatively level floors, or refuse was used for leveling. Floor coatings—usually one in number—curve upward continuous with the wall plaster. This faired plaster is a feature of many of the mid-1300 pueblos believed to have had Mogollon antecedents; it also occurred in eastern Arizona Anasazi sites beginning with Basket Maker III (cf. Martin and Rinaldo 1960:150). Daily floor sweepings were dumped "out front" to fill in a declivity between the central and south room clusters. This became a burial ground. Adjoining chambers were abandoned, razed, with some walls left in part. Refuse build-up continued, and became more and more mixed. Alterations and rebuilding took place.

In general, LA 25 masonry consists of somewhat irregular rock units, largely hand-shaped (but not dimpled), built into single-course walls, with a moderate amount of adobe mortar and some chinking with small pieces of sandstone. In one room upright slabs were set for some distance along two of the walls. Although the slabs here may be larger, the effect is similar to walls at Mesa Verde sites said to date between A.D. 1050 and 1150 (O'Bryan 1950:109, Pl. 16). The same can be said with regard ot Tsegi Phase sites in northeastern Arizona, which, however, date between A.D. 1250-1300 (Dean 1969:196).

Since none of the rooms excavated at LA 25 through Room 20 had any internal structures, there was no reason to anticipate that a chamber numbered 21, which roughly shared a corner with Room 20, would be of a different nature. None-the-less, all of a sudden one of the workmen brought his pick down on an unusually compacted chunk of adobe. Jumping to see the reason for this, we noted woody fragments amidst the dirt. Roof plaster and twigs? Not so! Careful cleaning of the area revealed the top of a well-built upright altar, or deflector of a fire pit-vent complex. We later deduced that the woody bits were from three erect poles that had been laced together and then plastered over. With this discovery of a rectangular, above ground chamber built within a north-south oriented house block, the idea that we might be working in a site reflecting Mesa Verde culture was dispelled. These were good Tewa features.

In the east wall, back of the deflector/altar and about 18 cm. above the floor, two small vent holes, 15.6 and 16.9 cm. in diameter respectively were revealed. They were tightly plugged with pieces of sandstone and adobe. In order to clean them out, the adjoining room to the east (No. 24), which already had been cleared to some extent, had to be excavated to bedrock. Resting near the deflector in Room 21 were two conical representations of the Corn Mother, fashioned of adobe. These and several similar fetishes recovered from a number of rooms, resulted in the site being designated as Las Madres. When the neatly plastered-over fire pit in front of the altar was cleared, a fine full-grooved stone maul was found in clear ashes. It is a type of specimen found in many

Anasazi ruins. Beams recovered from this chamber, although incomplete, indicate it to be of late construction/remodeling—after A.D. 1355. It remained unique among the fify-five rooms dug and analyzed at Las Madres. Its fire pit was the only one found.

The refuse areas were excavated stratigraphically, trench by trench, to determine for certain that no circular, subterranean kiva of the Mesa Verde Anasazi type existed. We also tested places on and around the promontory, and excavated a circular structure which had an opening toward the east by south. A rectangular room adjoined it on the west, and that room had a doorway on the south. This unit is less than 215 meters from the pueblo. The circular, unroofed building is a feature common to several other Galisteo sites, five of which I located. One is at the better known ruin of San Cristobal, where it is double-walled. These remind one of the circular, open structure at Wupatki in Arizona.

Evidence mounted that the people dwelling at Las Madres were hard-working but poor. They raised maize and squash, but little more than enough to eat, season by season. Hunting and gathering supplied supplemental foodstuffs. The mortality rate was high. No rooms were stored with produce; and only one small subfloor pit was discovered, that in Room 16. From this, three sizable sacks of "stuff" were removed: piñon shells, a pumpkin seed, very tiny animal bones, and a fine knife of silicified wood—which is plentiful in the region. Dendrodates indicate that this room was roofed very near A.D. 1350 (Robinson, Harrill and Warren 1973:50).

As at Pueblo Largo, the evidence at Las Madres has been studied in detail. It is revealed that further research must be pursued and many traits accounted for. We have a long list of dissimilarities between Las Madres and Mesa Verde sites (We have many traits that are known from Western Pueblo and from Mogollon sites;) and I detect certain features that may derive from the Hohokam. We have brown pottery clay figures and miniatures. We have cist burials and one of a type for which I seek comparative data: flexed human remains placed on one side, with a curbing built along the back in) form—the spinal curve—with a rock placed at the back of the neck and/or mid-back. The skulls have lamboidal deformation. We have woven matting and textile pieces and leather fragments, together with evidence of basketry; shell ornaments; a set of four incised tubular bones of Warrior rites of ceremonial nature, which suggest status recognition of the individual buried there. In one instance, a half of a conch shell was found in a skull cavity. Lithic artifacts show a simple but distinct industrial tradition; untouched utilized flakes predominate. Many bone artifacts have been found. Bird bones reveal a "period of cultural transition"—a large number of species in comparison with Mesa Verde (L. L. Hargrave, personal communication). Mammal bones were preferred over avian for tools.

In tracing origins for traits found at Las Madres, many trails lead to the West and southward, into the Gila-Salt and old Mogollon and Hohokam sites. I located, on a Rio Galisteo terrace an ancient lithic site (LA 356) which has been dated to 7000 to 6000 year ago (Dutton 1972:2; Honea 1969). Studies carried on over the past decade or so place southern influences farther and farther north. More and more data suggest that Mogollon and Hohokam peoples, moving north and east by various routes, scattered over a wide expanse, and joined Tanoan and other groups, where their original ancestry seems lost from sight. Inasmuch as it is my belief that Southwestern peoples and their cultures were influenced sighnificantly by Mesoamerican traits, directly and indirectly, it would appear that ascertaining relationships between the Galisteo inhabitants and dwellers of regions closer to Mesoamerica might give some clues as to what became of certain in-between peoples—peoples not yet fully accounted for.

EDITORS' NOTE: Dr. Dutton currently is devoting her major time to assembling notes, manuscripts, and all related data which she has on the Galisteo Basin. Publications are being prepared and unpublished records will be desposited at the Laboratory of Anthropology, Museum of New Mexico.

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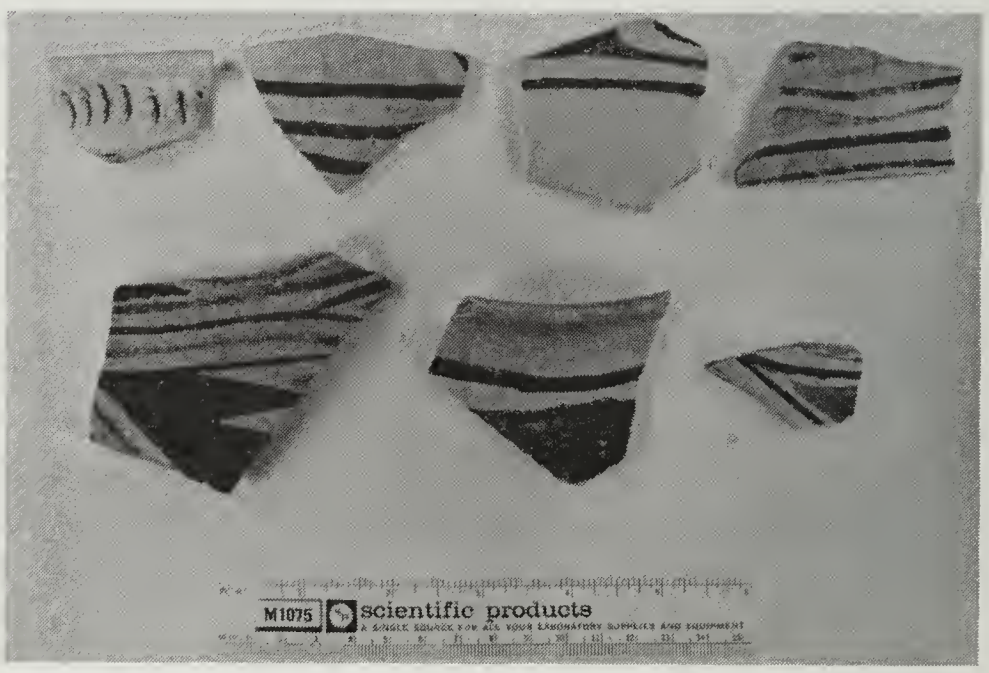
Ramos polychrome, standard variety

Huerigos polychrome

Ramos polychrome, capuline variety.



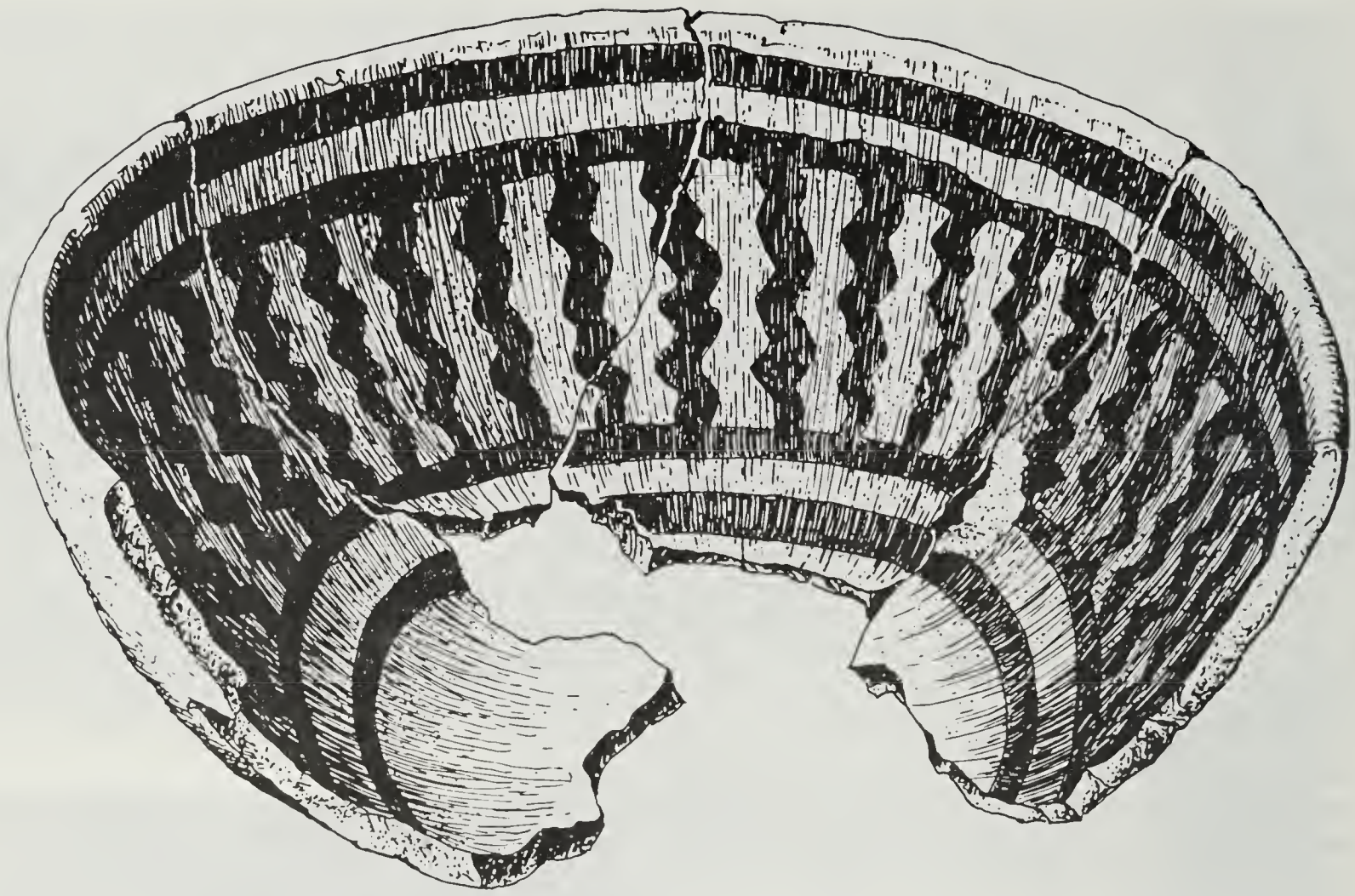
Babiacora polychrome

The location of Las Madres (LA 25) atop an exposure of the Galisteo Formation (yellow Ss.); standing walls to the right of the workmen. Transitional zone vegetation. View from West to East.

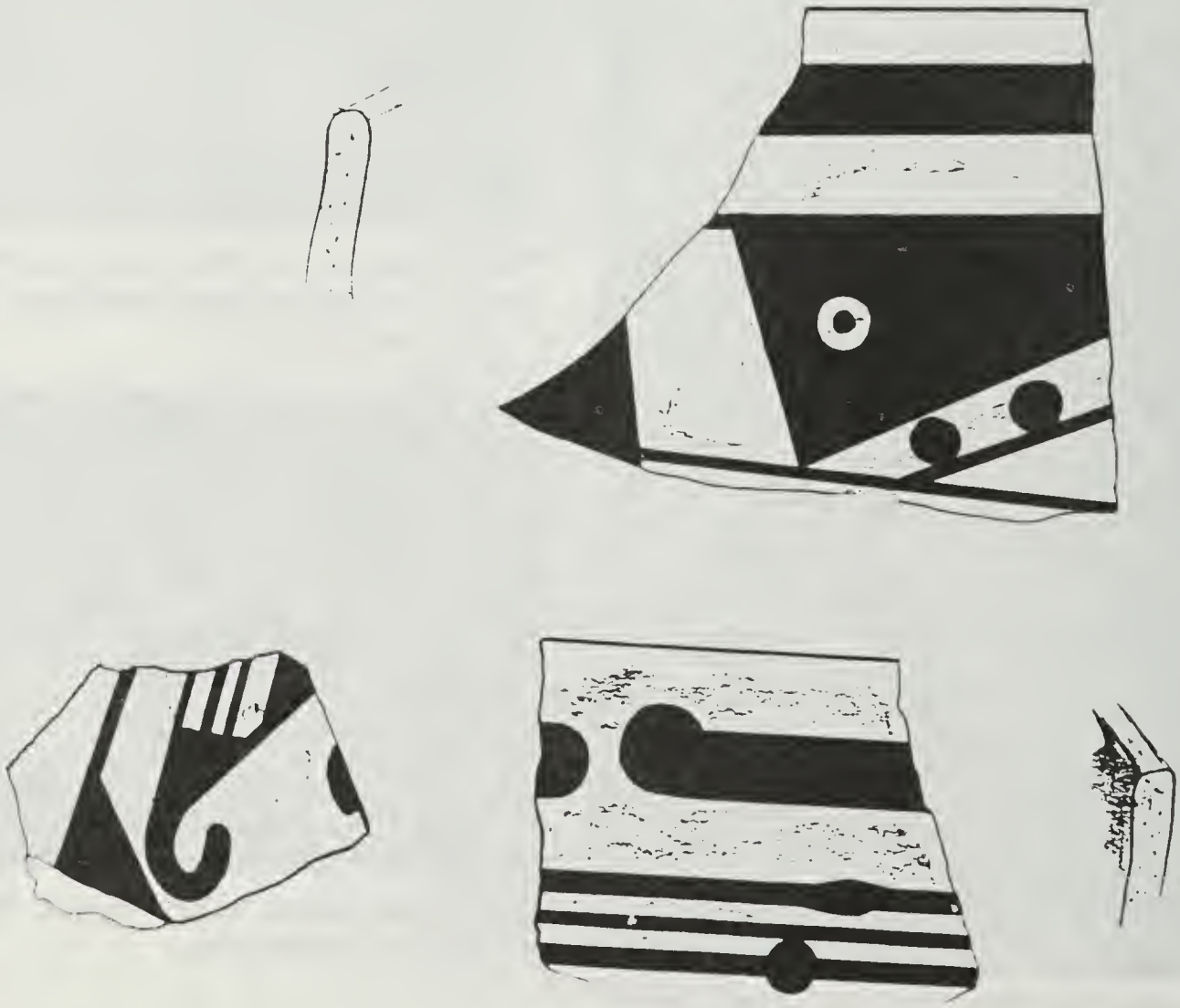
Pueblo Largo (LA 183). Kiva XX ventilator in Northeast corner. Typical masonry of the site.

Pueblo Largo (LA 183). Kiva A: Firepot, altar, ventilator (toward east) complex. Example of Rio Grande type kiva.

Pueblo Largo (LA 183). V-Tower. West to East. View up the Estacada.



Las Madres Black-on-white bowl (LA 25 10/30)



Western Pueblo designs that occur in Galisteo ruin sites.

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